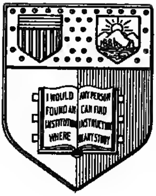
COAST SAND DUNES, SAND SPITS AND SAND WASTES.

By

GERALD O. CASE.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THE USE OF VEGETATION FOR RECLAIMING TIDAL LANDS.

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COAST SAND DUNES, SAND SPITS AND SAND WASTES.

BY

GERALD O. CASE,

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PREFACE.

The greater part of the coast line of the world is fringed with sands. In many places the wind blows the sand inland and causes the formation on the coast margin of belts of sand dunes. Such dunes, unless fixed by vegetation, travel inland, causing in time the formation of sand wastes, and in many cases erosion of the coast.

The object of this book is more particularly to draw attention to the advantages of collecting the inblown sand in the formation of a large coast protection dune, which when built up by the wind, under the guidance of man, to a proper height and inclination, serves several useful purposes. In the first place, such a littoral dune prevents inland sand drift and the formation of sand wastes; secondly, it acts as an embankment or line of defence against erosion of the coast; and, thirdly, it enables, and makes it commercially worth while, to reclaim and convert into beautiful pine woods, any existing inland areas of sand wastes or useless belts of sand dunes only partially covered by vegetation.

On the Continent vast areas of sand wastes have been reclaimed and are now productive pine forests. In Great Britain little attention has been given to the subject, and there are consequently round our coasts many square miles of sand wastes and large belts of unproductive dunes only partially covered with vegetation. In other places erosion of the coast is now taking place which could be cheaply prevented by the formation of a littoral sand dune embankment.

As no book on this important subject has hitherto been published in Great Britain, the author thinks no apology is needed for the present work.

The author desires to acknowledge his indebtedness to the Editor of *The Surveyor and Municipal and County Engineer* for permission to use matter which has appeared in that journal; to G. Garnons Williams, Esq., of Burry Port, Carmarthen; and the Foreshore Protection Company, Limited, of Westminster, for valuable information and photographs; and to the Geological Survey of Scotland for permission to reproduce photographs of the Culbin and Maviston sand wastes.

GERALD O. CASE.

9 North Street,
Brighton.
February, 1914.

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CHAPTER I.

INTRODUCTION.

In recent years considerable attention has been directed to the question of coastline changes, especially with reference to erosion caused by waves and currents, but little, if any, has been given to the powerful influence of the winds on sandy coasts. On such coasts the wind is a very active agent in causing coastline changes, resulting either in reclamation of land from the sea or the erosion and devastation of the land.

The wind has in many parts of the world built up wide areas of sand dunes or hillocks (also known locally as "links," "greens," "towans," "denes," "downs," "bents," "starr hills," "burrows," "warrens," and "moels"). The inblown sand in numerous places in front of low-lying lands has been formed into a dune embankment, and if fixed by vegetation, either naturally or by man, has resulted in the reclamation from the sea of large areas, which, but for the sand embankment, would be overflowed at every high tide. In conjunction with waves and currents, wind action plays an important part in the formation of sand spits, which in many instances form natural protecting breakwaters to navigable waterways.

In other places, such as on the Lancashire coast, the inblown sand has become more or less fixed by vegetation, and a succession of dunes or small hillocks of blown sand have been formed, resulting in the sea being pushed back. In the past 300 years the wind has formed a belt of sand from 1 to 4 miles wide between Formby and the Ribble estuary. Where there is insufficient vegetation to fix the sand dunes properly as they are brought into existence on the coast margin, they are rapidly moved inland, causing large areas of fertile land and even villages to be completely overwhelmed by the advancing sand; and sand deserts as a consequence are formed. In many places the inland movement of the unfixed dunes has resulted also in the migration of high-water line, causing serious erosion of the coast, as well as the devastation of the land.

Around the coast of Great Britain, and in fact all over the world, there are large areas of sand dunes which are only partially fixed by vegetation, and which might be made into valuable grazing lands if properly reclaimed.

There are three ways in which human industry can be applied to coast sand dunes. Firstly, the actual formation of a coast dune where coast erosion is taking place, or in front of low-lying land for reclamation purposes; secondly, the maintenance of the coast protection dune when once formed, whether naturally or artificially; and thirdly, the reclamation of the landward dune area when the protection dune has been made secure.

Although the formation, maintenance, and reclamation of sand dunes is a matter which, on the whole, has been much neglected, there are, nevertheless, as will be seen later on, many striking examples of the utility of such works. On the Gascony coast of France coast sand dunes were formerly moved inland by wind action, causing the erosion of the coast, the devastation of the land, and the formation of a miniature Sahara. All this, however, has been changed by the work undertaken by the French Government, and instead of vast areas of bare desolate sand, there are now productive pine forests. The success of this work was largely due to the initiative of a

French engineer, M. Brémontier, who, over a hundred years ago, devised a system for fixing and reclaiming the Gascony dunes. The work undertaken consisted: firstly, in the formation of an artificial coast protection sand dune, and secondly, when the supply of sand from the shore was effectively trapped by the coast dune, in the reclamation of the inner dunes by the cultivation thereon of various plants, and afterwards of fir trees. The reclamation work was commenced on the land side of the protection dune, and gradually extended inland until the whole area was reclaimed and rendered productive.

In Great Britain there are many square miles of waste sand dunes which might be rendered productive, and in some places, such as the Culbin Sands, there are large areas of shifting dunes which are a menace to the surrounding country, destroying, as they do in their inland march, much fertile land and property. If systematic work was undertaken there is no reason why these sand deserts should not be reclaimed and rendered productive, and even in time a profit made thereby.

In other parts of our coasts where erosion is taking place the collection of the inblown sand in the form of a large protection dune might do much to prevent erosion at a small cost. For many years the Dutch have fully recognised the value of sand dune embankments for coast protection.

AREA OF SAND DUNES IN EUROPE.

According to Shaler*, nine-tenths of the coastline of the world is fringed with sand. Various other estimates have also been made of the areas of coast sand dunes in Europe. A writer in "Aus der Natur" (Vol. 29, 1864) puts the dunes on the islands and coasts of Schleswig-Holstein, North-West Germany, Denmark, Holland, and

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* Shaler, "U.S.A. National Geological Monographs, 1895."

France at nearly 2,560,000 acres; the sand dunes in Scotland at 134,400 acres; in Ireland at 268,800 acres; and in England at 1,600,000 acres. Andresen* estimates the areas of coast sand dunes in Denmark at more than 166,400 acres, the breadth in some places being 6 miles. The dunes of Prussia have been estimated to cover from 85,000 to 110,000 acres, those of Holland upwards of 140,000 acres, and those of Gascony more than 200,000 acres. Pannewitz states that the sand dunes of Europe, including the sand wastes, cover an area of 13,440,000 acres.†

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* Andresen, "Om Klitformationen."
† Marsh, "The Earth and Man."

CHAPTER II.

TRANSPORTATION OF SAND BY WIND ACTION AND FORMATION OF COAST DUNES.

SOURCES OF SUPPLY OF SAND.

The sand which is transported by the wind to form sand dunes is obtained from the foreshore between the tide limits. Difference of opinion exists as to the origin of the vast quantities of sand now found on the foreshore and sea bed. The sand of the sea shore consists essentially of the detritus of rocks. Generally speaking, quartz grains, varying from $\frac{1}{200}$ in. to $\frac{1}{34}$ in. in diameter, and having a specific gravity of about 2·6, are the most numerous. In some places, however, such as the coast of Normandy, they are purely calcareous. On the shores of Brittany and Saintonge they are of a mixed composition, and between the Gironde and Adour rivers the sand particles are generally quartzose.*

Numerous writers have expressed doubt as to whether the vast deposits of sand on the shore and sea bed are of recent formation. Some geologists ascribe them to diluvial action. Starling† holds that the sands of the German Ocean are a product of the "Great North German drift" deposited where they now lie before the commencement of the present geological period. In giving evidence before the Royal Commission on Coast Erosion, Mr. W. H. Wheeler, M.INST.C.E., stated that, in his opinion, a great deal of the sand now found on the coast was formed on the breaking up of the glacial period. The land was previousl covered with snow, several miles deep, and whe the snow melted it brought down and deposite on the sea coast an immense amount of sand. M: Wheeler thinks that this sand has been movin about ever since, and that it has not been derive from actions going on now. In the author opinion the enormous quantity of material erode from the coasts during the formation of the Cor tinental shelf is quite sufficient to account for th sand we now see.

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* "Memoires Sur les Dunes, Annales des Ponts et Chaussées, 1833."

† De Boden von Nederland.

At the present time sand is being formed b erosion of the coast and attrition of the detritu and from the land surface by subaerial agencie Attrition is constantly reducing the size of th shingle on the coast margin. When the particles ha reached the size of sand grains further attritio takes place at a very slow rate; this may be partl due to their being separated from one another b a thin film of water, which prevents actual cor tact when they are in motion; or it may be du to the reduction of the violence of impact betwee the particles, due to their very small mass. Pe haps a balance is struck when the particles a reduced to such a size that the impact is unab to disintegrate the material further. Wheth this is so or not, the fact remains that whi shingle pebbles are worn by attrition at a rapi rate, sand particles on the sea coast do not th suffer.

Subaerial agencies, wind, rain, frost, chemic action, and running water, have a powerful infl ence in eroding the land surface, and considerab quantities of sand are now being formed by di integration. Many rivers transport a large amou of material from the land to the coast. Mess Humphreys & Abbot, after making careful surve and observations, estimated that 750,000,000 cub. f of sand and gravel was annually transported b the Mississippi river along its bed to the sea coast.*

There are also a few other sources from which coast sands are derived. In parts of the Cornish coast, such as at Par, large quantities of sand have been formed from the refuse of the tin works, which were so extensive in former days in the valleys above. Near Port Errol there are large granite quarries which have been worked for the past sixty-five years. As all the unsuitable material and chips are tipped into the sea, millions of tons of material have been deposited on the coast. A large quantity of this granite detritus in the form of sand has been moved on to the shore at Cruden Bay, and subsequently transported inshore by wind action.

The dune sands on the Egyptian coast are derived from the disintegration of calcareous sandstone in the neighbourhood. This sandstone was apparently consolidated under water during an ancient period of subsidence, and afterwards raised by an upheaval. It is largely composed of land and sea shells mingled with quartz grains.†

On some of the West India Islands sand derived from the comminution of corals is formed into coast sand dunes. The sand at Carbis Bay, Cornwall, is composed of about 70 per cent of shell fragments. On parts of the Jutland coast and Long Island quantities of sand are found consisting almost entirely of garnet grains.‡

While engineers are generally agreed that sand is transported alongshore by wind waves, tidal currents, and wind currents, there is a great difference of opinion as to whether sand in appreciable quantities is moved on to the foreshore from the sea bed. Captain W. T. Maxwell, in giving evidence before the Royal Commission on Coast Erosion, stated that sand banks which were formed in deep water were sometimes moved inshore, and might consolidate with the coast.

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* "Report on the Mississippi River."
† Fraas, "Aus dem Orient."
‡ Andresen, "Om Klitformationen."

In the author's opinion there is no doubt that offshore winds cause a surface current seawards and an undercurrent shorewards which is capable of transporting sand from the sea bed to the shore. Mr. W. Shield, M.INST.C.E., who also gave evidence before the Royal Commission on Coast Erosion, corroborated this view. Records made at the Butt of Lewis lighthouse show that between the months of January and July offshore winds predominate. According to the evidence of local fishermen, great quantities of sand at that time of the year are moved inshore from deep water. There is a sand bank in about 36 ft. of water, on which the fishermen catch flounders. After offshore winds this is found to be eroded, sometimes as much as 9 ft., and an accretion of sand at the same time is found on the shore opposite the sand bank.

THE TRANSPORTATION OF SAND FROM THE FORESHORE TO THE LAND.

Dry sea sand is transported by the wind chiefly by rolling motion along the surface. Some sand is carried in intermittent suspension by a very strong wind, but the sand particles do not remain suspended for long.

Andresen* states that a wind with a velocity of 40 miles an hour is capable of raising particles of ordinary sea sand as high as the eyes of an average man, but then the sand is only moved in intermittent suspension.

When the wind blows over dry sea sand, ripples are formed; experiments made by Dr. Vaughan Cornish at the London Sand Blast Works, Grays

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* C. C. Andresen, "Om Klitformationen."

Inn-road, showed that such ripples are created whenever the sand is heterogeneous.*

Sand ripples are formed by the eddies which are created on the lee side of the larger grains, and which carry away the smaller grains and form the surface in parallel ridges. The windward slope of the sand ripple is usually a concave and convex curve, the slope being comparatively flat, and forming an angle of about 4 deg. with the horizontal, the leeward slope is partly a straight line and partly a convex curve, it is steep compared to the windward slope, and may form any angle up to the maximum angle of repose of sand.

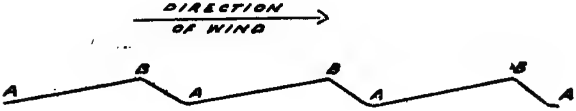

FIG. 1.—DIAGRAM OF RIPPLES IN BLOWN SAND.
The sand particles are driven by the wind up the slopes A B and fall by gravity down the slopes B A.

Sand ripples (Fig. 1) move forward by the grains being rolled up the long flat windward slope and falling by gravity over the steep leeward slope. The eddy on the leeward side assists, indirectly, in raising the height of the ripple by arresting the progress of the grains rolled up the windward slope.

The rate of movement of a sand ripple under the action of wind decreases with its increase of size, owing to the increase of the number of layers of sand. The rate of movement is consequently very slow compared to the velocity of the wind. Particles rolled up the windward slope, and falling down the leeward slope, are not acted upon by the wind again until the ripple has moved sufficiently forward to expose them again.

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* Dr. Vaughan Cornish, "The Formation of Sand Dunes," Geographical Journal," vol. ix., 1897.

THE FORMATION OF SAND DUNES.

Sand dunes on the coast line are generally formed by the accumulation of sand against some obstruction. Trees, shrubs, grasses, fences, walls, earth banks, &c., may occasion the lodgment of sand in considerable quantities.

Obstacles influence ~~the movement~~ of sand in two ways—firstly, they act directly as obstructions; and secondly, indirectly by affecting the motions of the air. When the sand is blown against a fence or barrier of vegetation it accumulates on the windward side, and an eddy is formed there which throws the finer grains to leeward. In this way accumulation takes place on both sides of the obstruction. In time the sand overtops it, the eddy on the leeward side assisting in the shaping of the dune. In the initial stage the obstruction has very much the same effect as the larger sand grains have in the formation of sand ripples. The wind makes an eddy on each side of a solid wall (Fig. 2), the eddy on the windward size tosses the finer grains, and the eddy on the lee side catches some of these. Sand, therefore, deposits simultaneously against both sides. If the sand is fine and the wind strong the accumulation on the lee side will be the greater. If the sand is coarse the accumu-

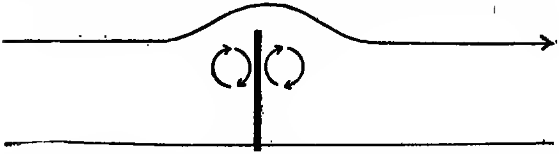

FIG. 2.—EFFECT OF A WALL ON THE COURSE OF THE WIND (AFTER CORNISH).

lation is chiefly on the windward side. That which is deposited on the lee side, being formed by sediment, has not the steep slope of the dune until the obstruction is buried in sand. If therefore the obstacle which occasions the accumulation of sand is a solid one, sand is at first dropped abundantly on its windward side as well as the leeward; but if it be an open fence or hedge the accumulation takes place chiefly on its leeward side.

While a fence of posts and rails or a brushwood hedge offers less obstruction than a solid wall, it causes eddies which are much more effective in bringing down the sand than those caused by a solid wall.

The shape of wind-formed sand dunes, when not interfered with, is much the same as that of sand ripples. The windward slope is usually from 4½ deg. to 10 deg. with the horizontal, and the leeward slope any angle up to the angle of repose of sand, and is often about 30 deg. with the horizontal. In places where artificial work is undertaken on the dunes, the slope of the seaward face varies considerably, but seldom exceeds 30 deg.

On all low sandy coasts, where there is a fairly wide expanse of sand at low tide, there is a tendency for sand dunes to form above high-water mark of ordinary tides. At low tide a certain amount of sand is dried by the wind and sun, and as soon as it becomes dry the wind is able to transport it inland. As a general rule, the prevalent winds are onshore, and such winds are more effective in moving sand inland than the less frequent seaward winds in moving sand back again into the water.

Brémontier estimated that on the coast of France between the Gironde and Adour rivers, 21·3 cubic metres of sand were annually transported per linear metre of shore. Laval, from observations made in 1824-32, put it at 25 cubic metres per linear metre of shore.* M. Dutemps du Gris, Conservator of Forests at Bordeaux, estimated it at 75 cubic metres per linear metre of shore.†

Above high-tide level sand is arrested by stones, grasses, trees, or other obstructions. Sand dunes may be formed by wind action alone; such dunes being frequent in Libyan and other deserts, but on the sea coast the formation of irregular-shaped dunes is chiefly due to vegetable life. The various kinds of grasses which grow in sand just landward of high water are very effective sand collectors. (Fig. 3.) Each plant, or group of plants, forms in effect an openwork fence, and collects sand in the manner previously described. Many of the various grasses which thrive on sandy coasts grow upwards as the sand accumulates; thus in time dunes of considerable size are formed.

The coast sand dunes between Gibraltar Point and the North of the Humber were to a large extent created by the action of vegetation.‡ At low tide considerable quantities of sand were blown inland by the winds. About high-water mark, grasses grew which arrested the wind-blown sand, and gradually the accumulation increased in size until a dune was formed 20 ft. or 30 ft. high. While this went on, various kinds of shrubs and trees commenced to grow and aided the grasses in retaining the blown sand.

On the sea coast, where the sources of supply of sand is a comparatively narrow strip of foreshore, the dunes, although often very irregular in size and shape, are generally in a line or lines more or less parallel to the shore.

Water in Sand Dunes.—The interior of sand dunes often contains water, and the tops are frequently found to be quite moist about 1 ft. below the surface. In the dunes of Algeria* water is so abundant that wells are constantly dug in them near the crests. The wells are sunk to a depth of 3 or 4 metres only, and the water in them rises to a height of 1 metre. Different authorities give various reasons for this humidity of the sand. Forchhammer† ascribes it to capillary attraction. Andresen‡ ascribes it to evaporation from below, and from experiments made he found that if a heap of sand was placed in water, the sand particles, after one night, were not moistened more than 8½ in. above the water level. He states that the minimum amount of water contained by the sand of dunes on the coast of Jutland, 1 ft. below the surface, was 2 per cent after a long drought, and 4 per cent after a rainy month, the amount of water increasing with the depth below the surface. He puts the hygroscopicity of the same sand at 33 per cent by measure, or 21·5 by weight. On the same coast the annual precipitation is 27 in., and the evaporation about the same.

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* "Annales des Ponts et Chaussées, 1824."

† Supplement to Bagnari's "Manual of Sylviculture" (English Translation).

‡ Report by S. Coetmore Jones, on Skegness, "Appendix to 1st Report of Royal Commission on Coast Erosion."

The water supply of the city of Amsterdam has for a long time been pumped from the neighbouring sand dunes.§ The physical causes which produce the supply of water is open to controversy, but Dutch engineers attribute it primarily to rainfall. Mr. Carey states that the water level in the dunes rises under capillary attraction, and from external sea pressure, and that 64 per cent of the rainfall is absorbed by the dunes and 36 per cent lost by evaporation, absorption due to vegetation, &c. The investigations of Mr. J. M. K. Pennink went to show that a part of this 36 per cent filters downwards and escapes laterally. It appears, however, that only a small part of the rain water finds its way directly into the sea.

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* Laurent, "Memoire Sur le Sahara."

† Forchhammer in "Leonhard und Brown's Neues Jahrbuch."

‡ Andresen, "Om Klitformationen."

§ Carey, "Minutes of Proceedings, Institution of Civil Engineers," vol. clxxxiv.

A comparison of the levels of the water in the sub-strata of the dunes, and of the fluctuations of the levels owing to pumping, has shown that a transition zone exists between the fresh and sea water levels in which brackish water is found. This transition zone is from 33 ft. to 36 ft. below the intake of the dune.

Stratification of Dune Sands.—In the interior of sand dunes the sand particles are often stratified. This, Marsh* suggests, may be partly accounted for by variations in the velocity of the wind. A strong wind will move from the shore to the dune sand grains of very different magnitude and specific gravity to that of a moderate breeze. The deposits of both the strong wind and moderate breeze might thus form a stratum. Another cause of apparent stratification might be the interposition of a thin layer of vegetable remains between successive deposits. In Jutland some of the coast dunes are composed of yellow quartzose sand intermixed with black titanian iron. When the wind ripples the sand surface, the crests of the ripples are composed of quartz grains, while the heavier iron rolls into the troughs, and thus, according to Forchhammer, the whole surface of some of the dunes appear to be covered with a fine black network.

Dunes in Lakes and Tideless Seas.—The existence of a foreshore at low tide is a usual, though not a necessary, condition for the formation of coast dunes. On the borders of Lake Michigan, in the Baltic and Mediterranean Seas, and elsewhere, coast dunes are found where there is practically no tide, and therefore no foreshore. On such coasts a certain amount of sand is constantly being washed in by the waves, and when the sand

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* Marsh, "Earth and Man."

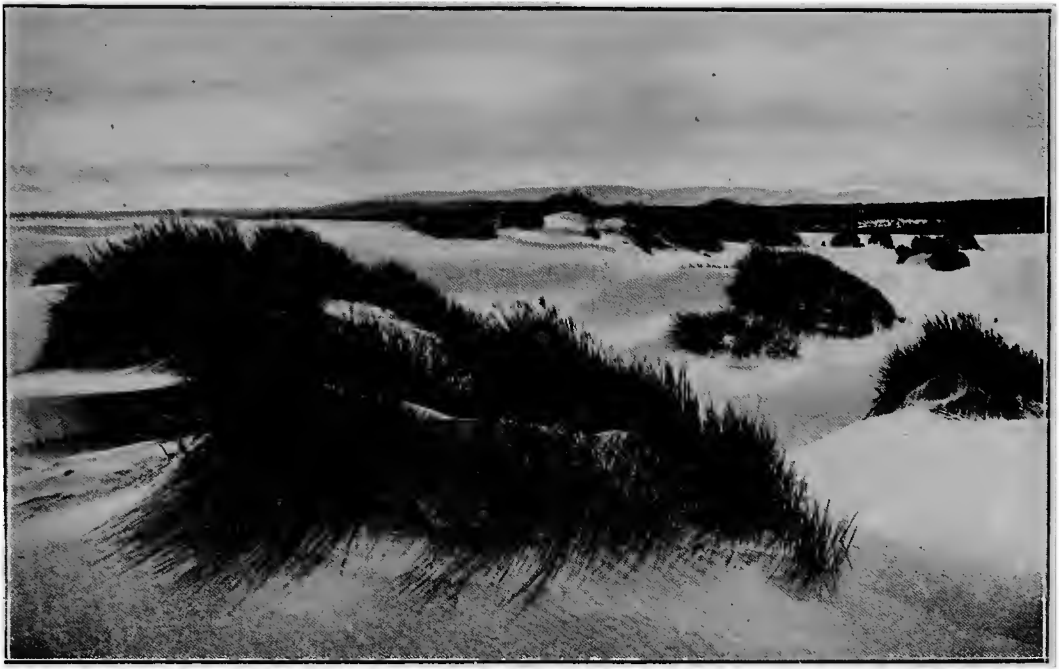

FIG. 3.—MAVISTON SANDS, ELGINSHIRE.

Tufts of marram grass arresting drifting sand and giving rise to dunes (Geological Survey of Scotland).

particles are out of the reach of the waters they are dried and then moved inland by wind action.

Sand Dunes Formed into Sandstone.—If sand dunes are fixed by vegetation for a long period there is a tendency for them to turn into sandstone. Sandstone embankments are, of course, a very permanent barrier against the encroachment of the sea. The sandstone is formed by water percolating through the sand and dissolving portions of shell fragments, the incoherent particles being cemented together. Cornish blown sand has in numerous instances thus become consolidated. The formation of sand dunes into sandstone is illustrated at Newquay. The water in this case percolating through the shelly ferruginous sand, dissolves the carbonates of lime, or of iron, which are redeposited as cementing materials on the evaporation of the water as it filters through the lower strata of the porous dune.

In Cornwall the coast sand dunes are frequently formed into sandstone which is hard enough to enable it to be used for building purposes. Although rather soft when first quarried, it quickly hardens when exposed to the air.*

Prof. Corstorphine, in the report of the Geological Commission (Cape Colony) for 1897, states that in the case of the coast sand dunes at the Cape the deposition of dissolved shells has gone on to such an extent that the resulting rock is really a limestone.

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* W. Topley, "Popular Science Review," vol. xiv.

CHAPTER III.

SAND DUNES IN GREAT BRITAIN AND ABROAD.

SAND DUNES IN GREAT BRITAIN.

The coasts of Great Britain are to a very considerable extent fringed with sand dunes. In most places where there is a wide expanse of sandy shore at low tide sand dunes have been formed, the height, width and slope varying very much in different localities. If the dunes are scantily clothed with vegetation the maximum windward slope is about 2 in 1, and the leeward slope the inclination of repose of sand. If more or less covered with plants the angles of the slopes and the shape of the dunes is often most irregular. In Great Britain the dunes do not generally attain to so great a height as they do in other countries. On the coast of Northumberland the dunes, which are often continuous for miles, are generally about 150 yds. wide, and the maximum height is about 70 ft. Between Winterton and Waxham the height varies from 30 ft. to 50 ft. In the Southport district, where there are over 20 square miles of dunes, the height varies from 20 ft. to 80 ft., and in some places the belt of them is 4 miles wide.

SAND DUNES IN CAPE COLONY.*

In various parts of Cape Colony there are extensive areas of coast sand dunes. At the Cape Flats, near Cape Town,† they were formed from sand blown inland by the wind from the shore at False Bay. The sea deposits on to the foreshore considerable quantities of sand, which are carried along this part of the coast by the waves and cur-

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* C. H. D. Breine, Reclamation of Drift Sands in Cape Colony, "Minutes of Proceedings, Institution of Civil Engineers," vol. cl.

† Memorandum prepared by Mr. Hawgood, 1876.

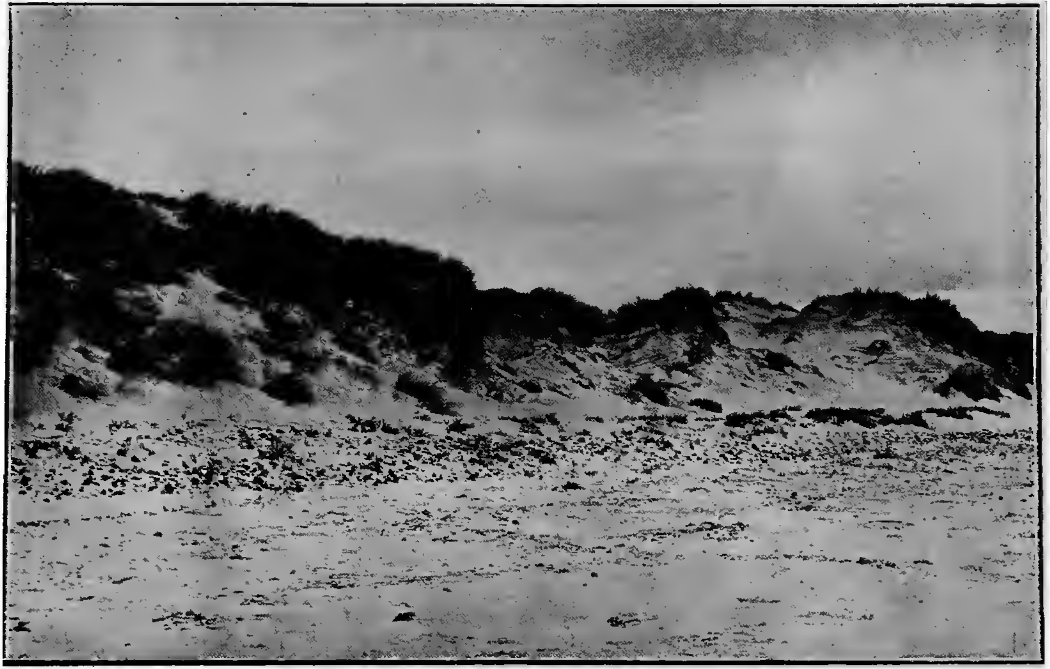

FIG. 4.—BURRY PORT, CARMARTHEN.

Sea side of sand dunes.

rents. At low tide the sands are quickly dried by the wind and sun, and then blown inshore by the south-west wind, and sand dunes are formed above high-water mark. The windward side of these dunes has a maximum slope of 2 in 1, and the leeward side a slope of about 1 in 1, their crests being about 4 ft. 6 in. wide.

Between Port Elizabeth and Algoa Bay there is a large extent of sand dunes, the total area of these sands being about 14,500 acres in 1890. The maximum height of the naturally formed dunes is about 46 ft.; most of them, however, are not more than 20 ft. high. Here the inland movement is in a north-easterly direction, the prevalent onshore wind being from the south-west. From statistics compiled in 1897-98 for the harbour engineer, it appears that for 183 days or part of days the wind blew between the south and west with a velocity of over 20 miles an hour, and on 74 other days it blew in the same direction with a less velocity, making a total of 257 days in a year in which the wind blew from the south-west. On 78 of these days the velocity reached or exceeded 40 miles an hour. The south-east winds during gales on this part of the coast are usually heavily charged with moisture, and consequently they have little effect in moving the sand.

SAND DUNES IN MADRAS.

Between latitudes 10 deg. and 16 deg. N. there is a long expanse of coast in the Madras Presidency where there is a sandy belt between high-water mark and the cultivated land.* It is separated from the land in some places by a level stretch of ground, which is liable to be flooded, and in other places by salt-water lagoons. This part of the coast faces due north and south, except for a slight easterly trend for about 150 miles.

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* R. Ryves, "A Sandy Belt on the Madras Coast," *Engineer*, February 2, 1912.

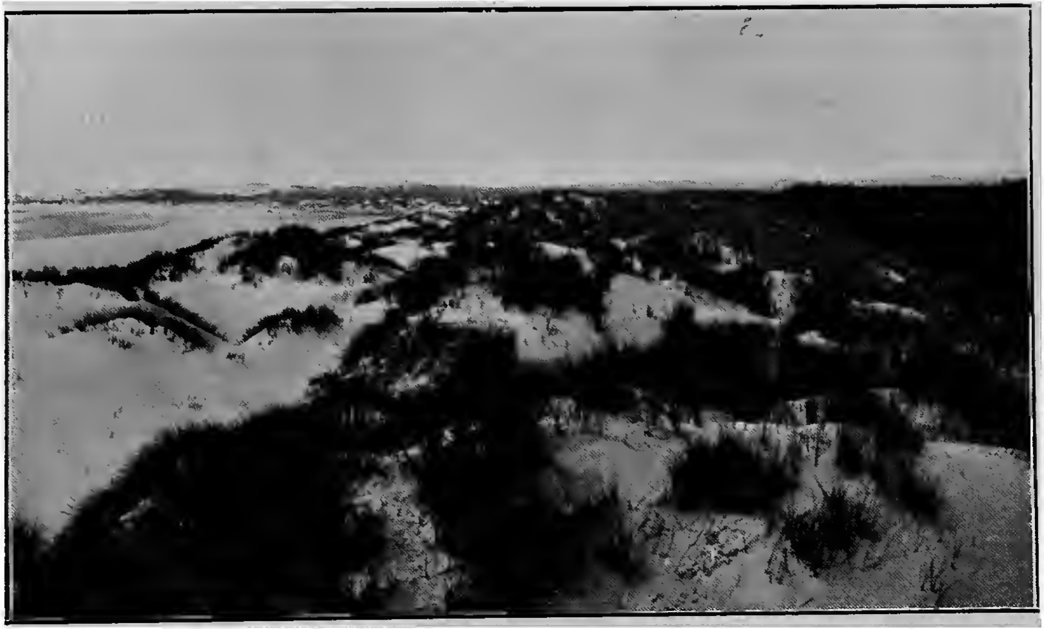

Fig. 5.—Sand Dunes, Burry Port, Carmarthen.

The sandy belt is only cut through by the large streams, many miles apart, and the mouths of these are often closed by bars for the greater part of the year. The material out of which this sandy belt is formed consists of sand, with which is some silt; it is brought down by the rivers, distributed alongshore by currents, and carried landward by the waves. The material thus thrown up is dried by the sun, and then transported by the wind.

The alternating alongshore currents which transport the sand are set up by the south-west and north-east monsoons. The tendency is to the formation of a continuous sandy belt, rather than of large groups of sandhills in one place.

For a part of the dry season there is a steady land wind for some time each day, and a similar sea wind for the remainder. There is a gradual travel of sand inland, but this is not so great as in places where there is a prevalent onshore wind, and it is lessened to some extent by the dampness of the wind during the north-east monsoon. As there is a considerable supply of sand brought in by the currents and waves, and not much tendency for the devastating inland movement noticed on other coasts, the sandy belt has increased in width.

SAND DUNES IN AMERICA.

On the east coast of the United States of America there is an almost continuous line of sand dunes, which in many cases protect marsh land lying between them and the mainland. In some places there are lagoons between the dunes and the mainland. The dunes extend continuously for more than 100 miles in certain parts.

On the Atlantic Coast the conditions are not so favourable to the formation of these natural sand embankments, as the prevalent wind blows from the west; but, nevertheless, long stretches

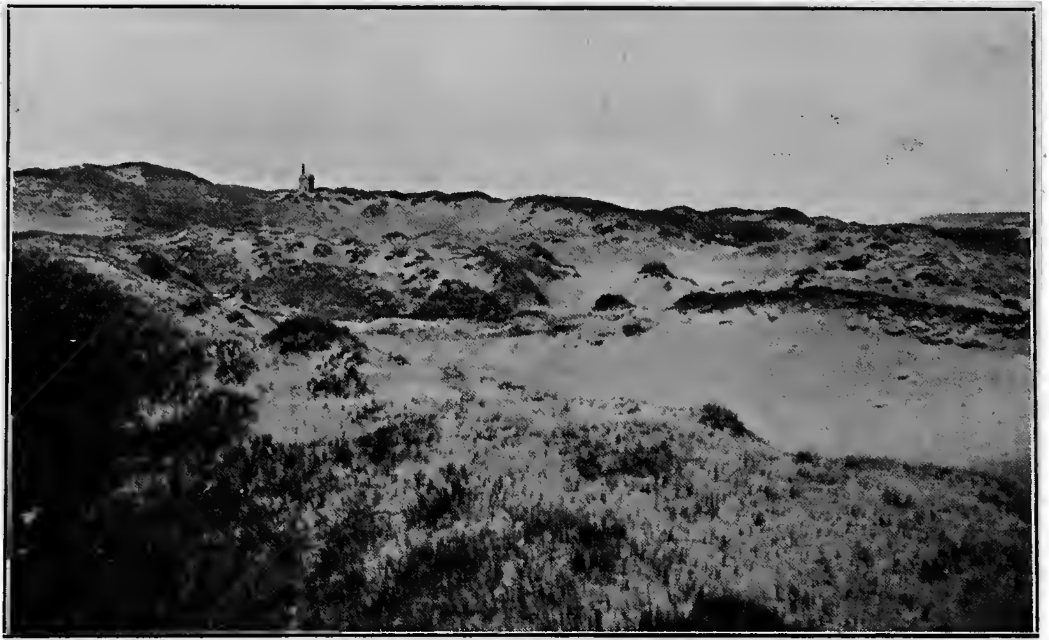

FIG. 6.—SAND DUNES, PENHALE, CORNWALL.
(Geological Survey of England.)

of them are found wherever the coastline, owing to irregularities in outline, is exposed to westerly winds.

On the south side of Long Island sand dunes extend continuously for 100 miles, and vary in height from 5 ft. to 30 ft. Ranges of them fringe the coast from New Jersey down to Chesapeake, and from Key West as far north as Jupiter Inlet.

The great dunes of the Essex district derive their sand from the long stretch of shore between Portsmouth and the Annisquam River in Massachusetts. The seaward extremity of Cape Cod is largely made up of wind-blown sand, on which whortleberry bushes are found. The " Banks " of North Carolina afford a typical example of island dunes. They are from 15 to 25 miles distant from the mainland, and enclose the waters of Pamlico Sound. On the east side of Lake Michigan sandhills rise to a height of from 100 ft. to 200 ft. above sea level.

SAND DUNES IN FRANCE.

The coastline of France for many miles is fringed with sand dunes, and before the work of fixing them by vegetation was undertaken by the State, the dunes travelled inland at a rapid rate, causing not only the devastation of large areas of fertile land, but also the inland advance of high-water line.

Between Biarritz and the mouth of the Gironde sand dunes extend for about 150 miles, having an average width of about 3 miles and a maximum height of about 300 ft.

SAND DUNES IN HOLLAND.

A great part of the coast of the Netherlands is bordered by sand dunes, and they are found on the coasts of the islands of Rottum, Schiermonnikoog, Ameland, Terschelling, Vlieland and Texel. Between the Hook of Holland and Scheveningen

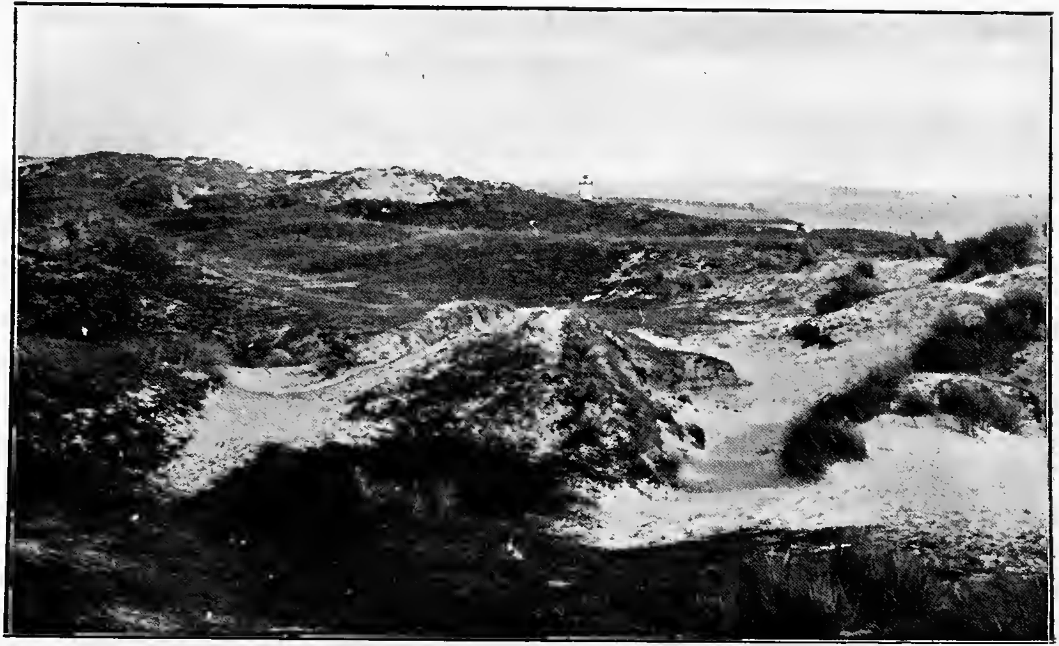

FIG. 7.—PEMBREY HARBOUR, CARMARTHEN.

Landward sand dunes which have become partially covered with turf.

the belt of dunes is generally about 1,950 ft. broad, but at Arendsduin is considerably less than this.* From the Scheldt to Texel the belt of dunes varies from 1 to 3 miles in width, and the height of the dunes varies from 40 ft. to 50 ft. They decrease in size towards Texel.

SAND DUNES IN BELGIUM.

Sand dunes are to be found on nearly the whole of the Belgian coast. In the neighbourhood of Nieuport the dunes are nearly 1 mile in width, and generally vary in height from 50 ft. to 80 ft., although in one place they are 114 ft. high. Towards Ostend the dunes diminish in height, and almost disappear at Mariakirke. Between Mariakirke and Ostend they are about 500 ft. wide. Northward of Heyst they are about 900 ft. wide, and on the west side of the Scheldt about three-quarters of a mile wide, and from 50 ft. to 80 ft. high.*

Sand dunes, unless fixed either naturally or artificially by vegetation, move inland in much the same way as sand ripples, previously described. The velocity of the inland travel of a coast dune is the rate of advance of the crest, which takes place by the accumulation of sand on the steep lee slope. The supply is brought in two ways; Firstly, by the rolling of coarse sand grains over the crest; and secondly, by the deposit of part of the flying sand caught by the eddy and not tossed away again.

If the sand composing the dune is both coarse and fine, the rate of travel is not proportional to the strength of the wind; for several sizes of sand which a moderate wind will roll up the windward slope will be whirled in intermittent suspension by a strong wind. Only in the case of an old dune containing scarcely any fine sand is the velocity nearly proportionate to the strength of the wind.

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* **Appendix to Third Report of Royal Commission on Coast Erosion.**

The rate of travel of unfixed dunes varies very considerably in different localities. The church of Lege, France, had to be pulled down at the end of the seventh century owing to the inland movement of the sand dunes, and was rebuilt 2½ miles inland; 160 years afterwards it had to be moved again, showing an inland movement of the dunes at the average rate of 81 ft. per annum.*

Before they were fixed by vegetation the dunes between the Adour and the Gironde rivers, in France, moved inland at the rate of from 16 ft. to 90 ft. per annum, and in their progress buried extensive fields and villages.

On the western coast of Jutland and Schleswig-Holstein the inland movement of the sand dunes formerly took place at the rate of from 3 ft. to 24 ft. per annum, burying many buildings and much fertile country.

On the coast dunes at Eerste River, Cape Colony, experiments were made some years ago to ascertain the rate of inland movement of the unfixed dunes. For this purpose six typical dunes were chosen, and posts 10 ft. in length were fixed at ninety-one stations on the top of the dunes. After eight months the movement at one station was found to be 300 ft., but at forty other stations it did not exceed 50 ft. Measurement taken after twenty months showed a total movement of about 500 ft. at two stations. From these experiments one of the Forest Department officers estimated that at the Blue Down Sands the mean inland movement was at the rate of 80 ft. per annum.

At Cape Flats, from observations made by Mr. Hawgood, it appears that there the annual rate of inland movement of the unfixed dunes was 60 ft. per annum. Observations were made at Port Elizabeth on the rate of movement of two dunes in 1898 and 1899, and these showed the rate of inland travel to be about 50 ft. per annum.

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* W. H. Wheeler, "The Sea Coast."

CHAPTER IV.

DEVASTATION CAUSED BY THE INLAND MOVEMENT OF SAND DUNES.

The inland movement of sand dunes has caused in the past, and in fact is causing at the present time, the devastation of enormous areas of fertile land, and the dunes have buried in their progress houses and in some places villages of considerable size.

Sand Wastes in Great Britain.—In 1668 part of Santon (Sand-town), Downham, between Brandon and Thetford, in the county of Norfolk, was overwhelmed by sand drift. In the course of a century the sand travelled four miles, and covered more than 1,000 acres of land.*

In Cornwall we find several examples of land and buildings being overwhelmed by sand. At Perran Sands the inland sand drift has buried several square miles of undulating ground. Constantine's Church, situate near Travose Head, founded by St. Piranus, the Irish Bishop, was for seven centuries buried in blown sand, but became uncovered in 1835. The churches of Gwythian and Perranzabuloe, Cornwall, were at one time covered by blown sand, and were afterwards laid bare by the further inland drift of the sand.† At Kenfig, in South Wales, sand dunes now cover the site of a village which in historical times was overwhelmed by blown sand.

Sand Wastes in Ireland.—Mr. J. R. Kilroe, A.R.C.S.I., in a memorandum prepared for the Royal Commission on Coast Erosion, states that there are few of the many tracts of blown sand met with around the north-west coast of Ireland, where tenants of the adjoining cultivated and pasture lands do not speak of some damage accruing from inland sand drifts. In the past thirty years much of the sand forming the dunes at Mullaghderg, on the coast of the Rosses, North of Dungloe, has been drifted away by the wind.

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* *Vide* W. B. Woodward, F.G.S.. "Geology of England and Wales."

† W. Topley, Sand Dunes and Blowing Sand, "Popular Science Review," vol. xiv.

A range of high sandhills crosses the Gweebara estuary at its embouchure. Formerly a stone could be thrown from north to south across the river mouth; now the sandhills on the north side in Dovey are rapidly reducing in width and height. On the south side the sand dunes used to be up to 40 ft. in height, but are now not more than 20 ft. high. The sand from these unfixed dunes has been blown inland to the detriment of the pasturage. A ridge of sand dunes formerly extended westward almost to the Island of Inishkeel, near Portnoo, west of Maas, upon which island stands the ruins of a church. The sand dunes are now about a quarter of a mile from the island, which is accessible by a low strand at ebb tide.

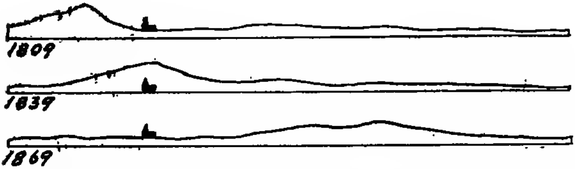

FIG 8.—DIAGRAM ILLUSTRATING THE MIGRATION OF DUNES ON THE KURISCHE NEHRUNG.

(Credner Elemente der Geologie.)

Rutland Island has been completely devastated by sand drifts at no distant date. Lord George

Hill, in his book on Donegal, states that until about 1806 this island was quite green, and had on it a military station and some good houses.

A large accumulation of blown sand rests on the southern slopes of the high ground forming the promontory of Horn Head. This sand is constantly being drifted north-eastward, with the result that the principal road entering the promontory is sometimes rendered impassable. The sand dunes have been lowered as much as 30 ft.*

Between Rosguill and Carrigart a large area of land has been covered by sand blown from the Campion sands. One little village has been completely buried under the sand.†

Sand Wastes in Scotland.—On the south coast of the Moray Firth there are extensive areas of sand wastes known as the Culbin and Maviston Sands.‡ The old Barony of Culbin comprised an estate of about 3,600 acres, and was called the granary of Moray. Mr. Bain in his booklet on these sands says that if the estate had come down unimpaired to the present time its rental value would be at least equal to £6,000 per annum. In the centre of the estate stood a large mansion house, with extensive grounds of shady trees and orchards. There were sixteen farms and farm-houses, and numerous small crofts and huts on the estate. Now the mansion and farms are buried in the sand, and for 4 miles in length and 2 miles in breadth there is a great desert of sand consisting of a succession of dunes up to 100 ft. in height.

Hugh Miller in his "Sketch Book of Popular Geology" thus describes the sand wastes: "I have wandered for hours amid the sand wastes of this

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* J. R. Kilroe, A.R.C.S.I., Memorandum prepared for Royal Commission on Coast Erosion.

† "Memoirs of the Geological Survey of Ireland, 1891."

‡ G. Bain, "The Culbin Sands, or the Story of a Buried Estate." Sir A. Geikie, "The Scenery of Scotland." H. Miller, "Sketch Book of Popular Geology."

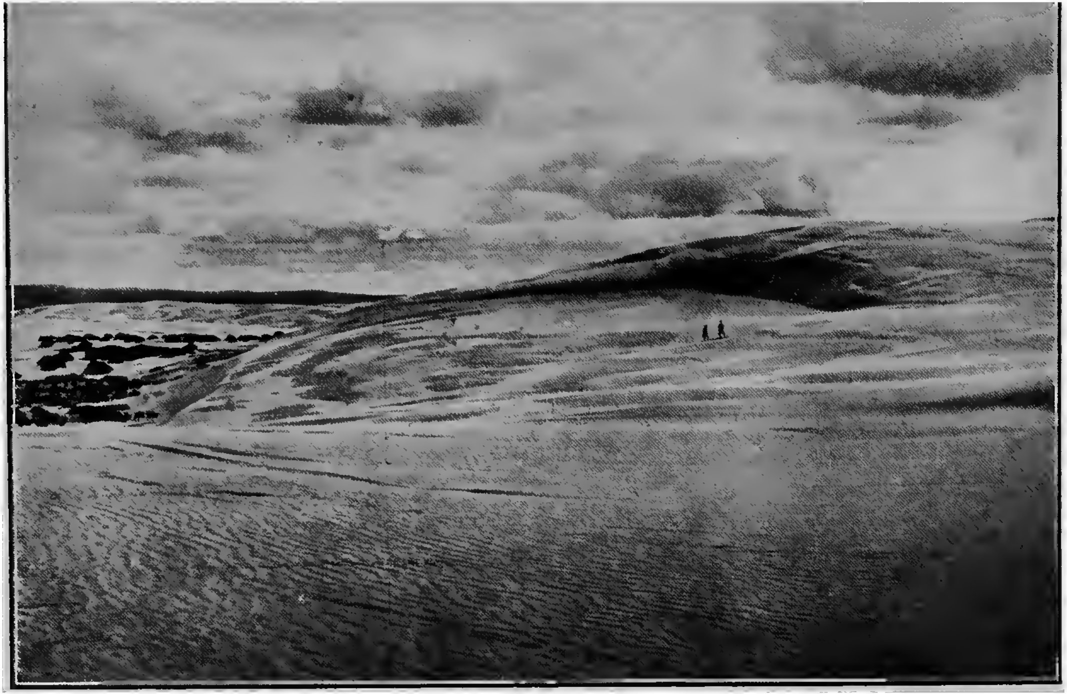

FIG. 10.—CULBIN SAND WASTES.

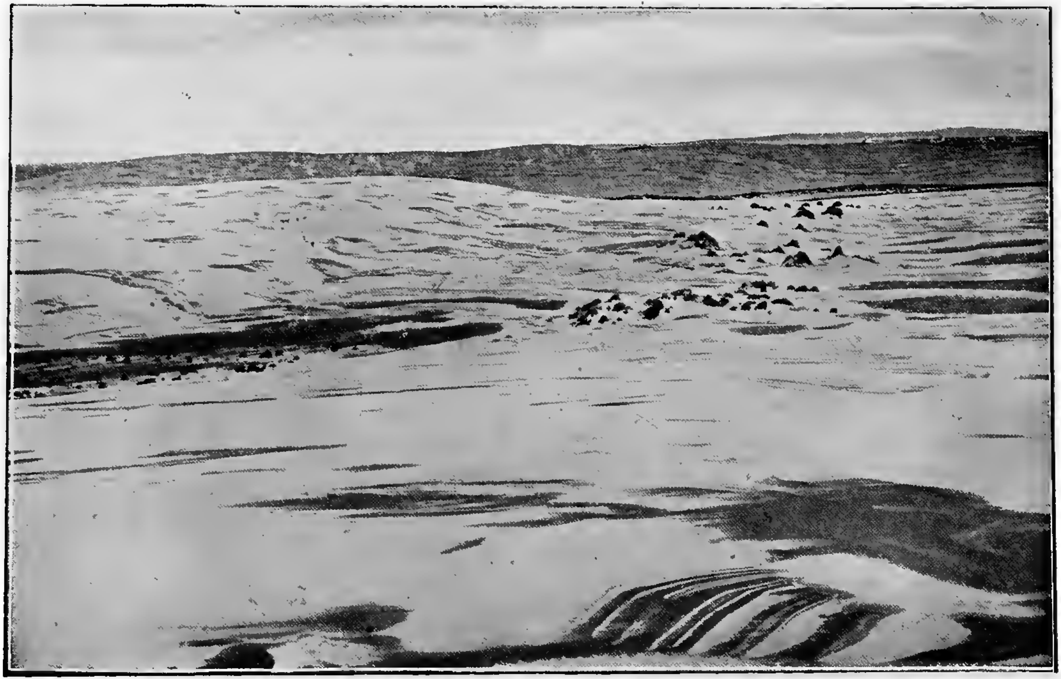

Fig. 11.—Culbin Sand Wastes.
Drifting of Sand over Damp Surface after a Heavy Shower of Rain.
(Scottish Geological Survey.)

ruined barony, and seen only a few stunted tufts of withered bent, occupying amid utter barrenness the place of what in the middle of the seventeenth century had been the richest fields of the rich province of Moray.''

The inland movement of sand had to some extent gone on for a number of years, and was in some measure due to the destruction of the vegetation on the dunes; but in 1694 a great storm drifted enormous quantities of sand inland with remarkable suddenness. In time the sand completely overwhelmed the mansion and other buildings. About 100 years ago a portion of the old mansion-house was uncovered by the movement of the dunes, but eventually it became covered again by a fresh dune.

The sand in this district is stated to be of a very fine powdery nature, and during storms clouds of sand are raised from the tops of the dunes. Mr. Bain states that "huge sandhills seem to disappear in a night of drift, and vast mounds are heaped up afresh."

Wide stretches of drifting sands also occur on the Aberdeenshire coast, and have buried considerable tracts. The road leading into Port Errol from the south has been frequently rendered impassable owing to the sand drifts, and houses on the sea side of the road have been seriously endangered.

Sand Wastes Abroad.—In many places all over the world large areas of coastal sand wastes have been formed by the inland movement of sand dunes. Cape Hatteras, Lake Michigan, and New Jersey furnish a good example of the devastating effect of the inland movement of dunes not properly fixed by vegetation. At Hatteras they have buried houses and filled up a swamp, although not exceeding 70 ft. in height; and it is probable that the island to the north of Cape Hatteras will soon be rendered uninhabitable. There are some places

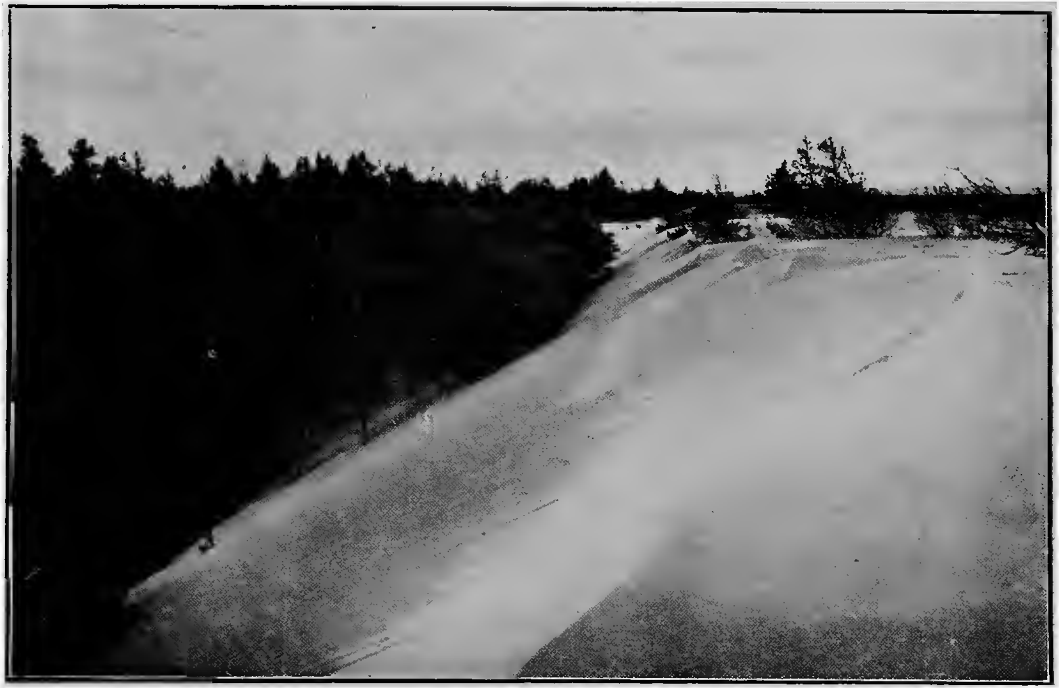

FIG. 12.—MAVISTON SANDS, ELGINSHIRE.
SAND DUNES MOVING INLAND AND OVERWHELMING A PLANTATION OF SCOTCH FIR
The flutings at top of slope due to arrest of sand by buried tops of trees (Scottish Geological Survey).

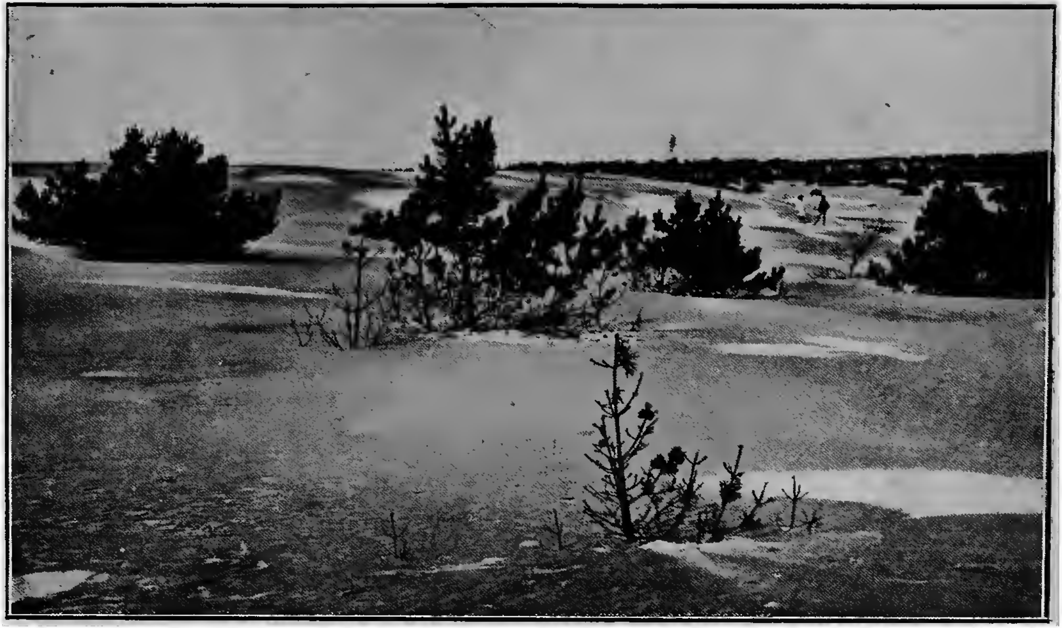

Fig. 13.—Maviston Sands, Elginshire.

The still-living tops of the buried fir trees marking the advance of the sand dunes (Scottish Geological Survey).

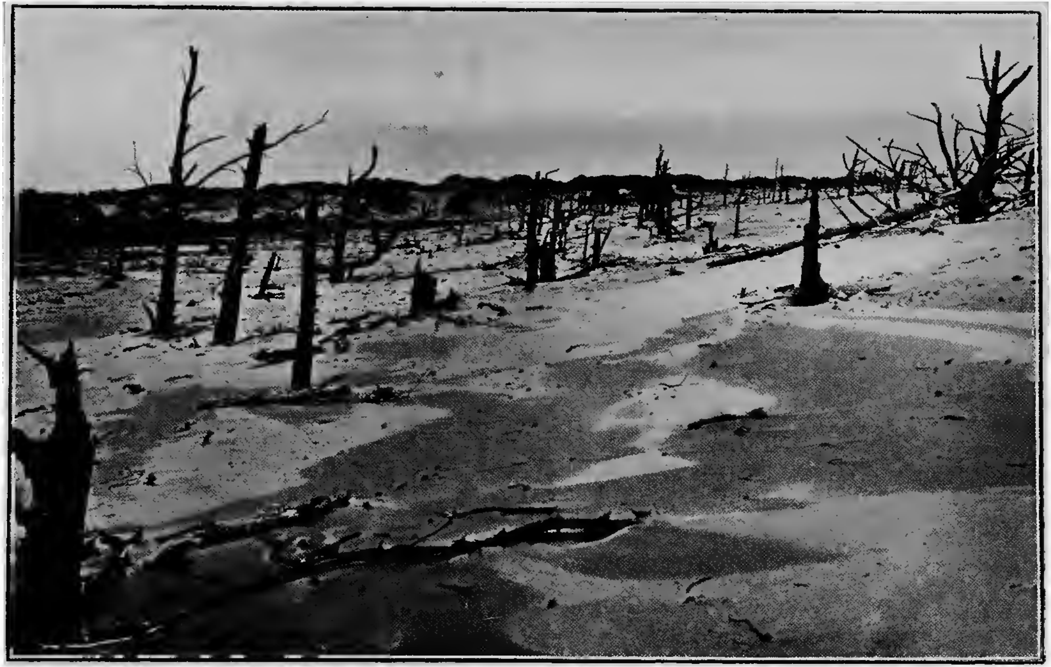

FIG. 14.—MAVISTON SANDS, ELGINSHIRE. REMAINS OF A FIR WOOD.

The sand dune, after burying and killing the fir trees, has been shifted beyond it (Scottish Geological Survey).

in New Jersey where orchards have been buried within the lifetime of their owners. At the head of Lake Michigan the inland drift of the dunes has covered a considerable area of fertile country.

In France there was formerly a very extensive sand desert. Marsh, in his well-known work "The Earth and Man," states that between the Adour and Gironde estuaries the belt of sand dunes varies from a quarter of a mile to 5 miles in width, and covers an area of 240,000 acres.

It is not known historically when the sands began to drift, but certain it is that they have buried extensive fields, forests, and thriving villages. They have changed the course of rivers, injuriously obstructed the natural drainage by choking up the beds of streams and forming pestilential swamps of considerable area. Clave thus describes the Landes of Gascony: "Composed of pure sand, resting on an impermeable stratum called *alios,* the soil of the Landes was for centuries considered incapable of cultivation. Parched in summer, drowned in winter, it produced only ferns, rushes, and heath, and scarcely furnished pasturage for a few half-starved flocks. To crown its miseries, this plain was continually threatened by the encroachments of the dunes. Vast ridges of sand, thrown up by the waves for a distance of more than 50 leagues along the coast, and continually renewed, were driven inland by the west wind, and as they rolled over the plain they buried the soil and hamlets, overcame all resistance, and advanced with fearful regularity. The whole province seemed doomed to certain destruction when Brémontier invented his method of fixing the dunes."

Lavergne* estimated the area of the Landes of Gascony at 1,700,000 acres. He states that when the Moors were driven from Spain by the blind cupidity and brutal intolerance of the age, they demanded permission to establish themselves in this desert, but political and religious prejudices prevented the granting of this liberty. At this period the Moors were a far more cultivated people than their Christian persecutors, and they had carried many arts—that of agriculture especially—to a higher pitch than any other European nation; but France was not wise enough to accept what Spain had cast out, and thus the landes remained a waste for three centuries longer.

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* "Economie Rurale de la France," quoted by Marsh.

Between the Pyrenees and the Baltic many fertile fields and houses have in the past been buried in drifting sand dunes.

SAND WASTES CAUSED BY MAN'S INTERFERENCE WITH THE NATURAL GROWTH ON SAND DUNES.

In many places on the Continent sand dunes have spontaneously clothed themselves with forests; Marsh states that "the rapidity with which their surface is covered by various species of sand plants, and finally by trees, where man and cattle and burrowing animals are excluded from them, renders it highly probable that they would, as a general rule, protect themselves if left to the undisturbed action of natural causes." Whether this view is correct or not, certain it is that large areas of moving sand wastes have been formed in consequence of man's destroying the forests growing on the dunes.

In the Middle Ages a great pine forest bound and securely fixed the sand dunes between Danzig and Pillau. When King Frederick William I. was short of money, a certain Herr von Korff promised to replenish his impoverished exchequer if he was given permission to remove the "useless" pine trees on the sand dunes. Permission having been given, he cut down the whole of the dune forests of Frische Nehrung, which were in Prussian territory. The King received 200,000 thalers, but the State suffered great injury, for the wind immediately commenced to move the bared sands.*

Documentary evidence seems to prove that the dunes of Holland were clothed with trees until after the Roman invasion. Old geographers describe vast forests extending to the very brink of the sea, the drifting sand dunes being first mentioned by chroniclers of the Middle Ages, and there is every reason to think that the formation of the bare shifting dunes was due to the improvidence of man.†

The dunes on the West Coast of Jutland were at one time covered by forests. The subsequent felling of trees resulted in the sand moving inland and burying a great extent of fertile soil.‡

Cape Cod furnishes us with another example of the devastating effects of sand drift following the destruction of vegetation. Over 1,000 acres in this neighbourhood was at one time enclosed and planted with beach grass. The gates of the plantation, however, were left open, and cattle destroyed the grass. As a result the sand commenced to drift away, and in places the surface was lowered to a depth of 10 ft.§ The Landes of Sologne and of Brenne were once composed of a forest of 1,200,000 acres. Subsequently the trees were cut down, and the Landes relapsed into their primitive condition of a barren sand waste. Measures were afterwards taken to reclaim them again.¶

The sand dunes at Rosepenna, Ireland, are of special interest, as their history illustrates the advantage of planting marram grass to fix sand wastes, and the disadvantages attending the disturbance of vegetation on sand dunes. Prior to 1850 these sand dunes were in a very unstable condition. About that time the late Earl of Leitrim planted some hundreds of acres with marram grass which effectively fixed the sands. The contrary effect found illustration in the previous century when Lord Boyne built a house on the dunes and attempted to till and to cultivate the then stable sands. The disturbance of the grass resulted in the sand drifting to such an extent that after a time only the chimneys of the house could be seen above the sand desert.

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* Müller, "Das Buch der Pfanzenwelt."
† Marsh, "The Earth and Man."
‡ Bergsoe, "Reventloos Virksomhed."
§ Dr. Dwight, "Travele."
¶ E. About, "Le Progrès," and Marsh, "The Earth and Man."

Between Belfast and Warrambool, Victoria, the coast dunes, when settlement first took place, and for some years afterwards, were covered with vegetation. The she oak (*Casuarina*) and honeysuckle (*Banksia*) grew in abundance. Afterwards the trees were cut down, and as a result the bare dunes drifted inland.*

The destruction of vegetation on the Culbin dunes has already been mentioned as one of the causes of the formation of the Culbin sand wastes. In 1695, in consequence thereof, an Act of Parliament (William and Mary, c. 30), applying to Scotland, was passed prohibiting the pulling of bent, juniper, or broom, to which cause it assigns the sand drift.†

In other countries laws have been passed to prohibit the destruction of vegetation on sand wastes. In 1539 a decree was passed by Christian III. of Denmark imposing a fine on anyone found guilty of destroying certain kinds of sand plants on the west coast of Jutland. This law was re-enacted and made more comprehensive in the year 1558.

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* T. E. Rawlinson, C.E., "Philosophical Transactions, Royal Society of Victoria," vol. xiv.

† Dr. Rampini, "History of Moray and Nairn."

In 1559 the inhabitants were required by Royal Rescript to do their best to check the sand drifts.

In 1826 an Ordinance was passed prohibiting the cutting of bushes or brushwood on the coast sand dunes in the neighbourhood of Port Elizabeth under a penalty of from £2 to £5, the object of this Ordinance being " to prevent the loosing and drifting of the sand over the adjacent country." The Port Elizabeth Harbour Act of 1872 also prohibited the uprooting of trees, bushes and fibrous rooted plants from the coast sand dunes.

CHAPTER V.

EROSION OF THE COAST RESULTING FROM THE INLAND MOVEMENT OF SAND DUNES.

In places where the sand blown inland from the foreshore is not replaced by sand brought in by sea action or littoral drift the erosion of the foreshore naturally takes place, the inland movement of the sand dunes being followed by inland movement of high-water mark.

In 1839 the ruins of Eccles Church tower were half buried in the sand dunes. By December, 1862, the sand dunes had moved inland, so that the ruins were on the shore between high and low water marks, and were destroyed by the sea in 1895.

The inland movement of the neglected sand dunes in the middle of the eighteenth century resulted in serious erosion of the island of Syet (on the west side of Schleswig). The church of the village of Rantum had to be dismantled, having been covered by the drifting dunes, and when they had moved further inland the foundations were washed away by the encroaching sea, which was eroding the coast at such a pace that fifty years afterwards the site of the church was nearly 900 ft. seaward of the shore line.*

The sand wastes which formerly existed on the Gascony coast of France have been previously described; there the supply of sand brought on to the shore by the sea was not sufficient to compensate for the sand moved inland from the foreshore by the wind, and consequently erosion of the coast and the inland movement of high-water line took place simultaneously with the inland movement of the dunes.

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* Andresen, "Om Klitformationen."

The ruins of the ancient town " Novio Magnus," which was situated opposite Soulac, were visible on the shore at low water in the sixteenth century. The erosion at the Pointe de Grave between 1830 and 1842 was about 200 yds., the lighthouse there having to be moved inland three times.*

The efficiency of vegetation in consolidating sand dunes and preventing coast erosion has for a long time been widely recognised, and numerous laws have been passed to prevent its destruction. Curiously enough, however, there is no Act of Parliament now in force preventing the destruction of vegetation on the East Coast of England, although the sand dunes in several places are the only protection against the encroachment of the sea.

In the reign of Queen Elizabeth an Act was passed to prohibit the destruction and to encourage the cultivation of vegetation on sand dunes. An Act of Parliament (15 George II., c. 33) was also passed in 1741 to prevent the cutting of starr, or bent (marram grass), on the sandhills of Scotland and the north-west coast of England. It recites (sec. 6) that the best way to preserve the sandhills upon the north-west coast of the Kingdom, and especially in the County Palatine of Lancaster, which formed a barrier against the encroachments of the sea, was to plant the same with a certain rush or shrub called starr, or bent, which kept the sandhills solid, and that persons had been accustomed to cut down the starr, or bent, for the purpose of making mats, brushes or brooms. A penalty of 20s. was imposed on those who, without the consent of the lord or owner of the starr, or bent hills, cut the same on the hills or banks of the north-west coast of England, the Justices being empowered to summon the offenders. Under sec. 7 a penalty was imposed on any persons found with starr, or bent, in their custody. Sec. 8 contains a proviso that the Act should not extend to persons entitled by prescription to cut starr, or bent, in Cumberland.

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* Marsh, "Earth and Man."

In early times there were laws in force in numerous manors in England to prevent injury to coast sand dunes.* The Records of the Manor of Ingoldmells, in the County of Lincoln,† show that in the reign of Edward II. five Orders of Attachment were made against various persons for "doing damage in pasturing on the sea banks, for mowing the dunes and herbage outside the bank of the sea, against the defence of the sea, for the salvation of the country, at the Manor of Ingoldmells." An entry in the records under the date October 24, 1325, shows that the tenants were bound not to do anything which might destroy the vegetation on the sand dunes, for one, William Elrikes, was on that date "destrained by four cows, because he mowed the brambles on the outside (seaside) of the sea bank, which is the defence of the whole community of the vill of Skegness."

In Holland, and other European countries, laws have also been enacted for the careful preservation of the grasses that are efficient in binding the sand dunes.

The advantages of vegetation for protecting the coasts from erosion have long been recognised in America. The planting of grasses, shrubs and trees has been practised since Colonial days, and numerous laws have been made to preserve vegetation on the coast dunes. On December 16, 1758, an Act was passed to prevent the destruction of plants and trees on coast sands, and it also prohibited farmers from turning cattle out to graze on the dunes, at Long Island and elsewhere, which formed a natural protection against coast erosion. The Act was entitled "An Act to restrain the feeding of cattle, burning grass and cutting the timber on certain beaches and islands therein mentioned." It was renewed repeatedly in Colonial times, and also by State law in 1789.

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* G. A. Sinclair, "Scottish Historical Review," July, 1910.

† Rev. W. O. Massingberd, M.A., "The Court Rolls of the Manor of Ingoldmells."

THE UTILITY OF VEGETATION FOR FIXING SAND DUNES.

In collecting, above high-water line, sand blown from the foreshore, vegetation plays a very important part in preventing coast erosion. Sand dunes, as previously mentioned, move inland if unfixed by vegetation, and fresh dunes are often formed which, in their turn, travel inland. As the sand is removed from the foreshore serious erosion may result by its continued depletion. If covered with vegetation, sand dunes form a consolidated barrier against the encroachment of the sea. The roots of the various grasses and plants bind the surface, and the foliage catches and retains sand abstracted from the foreshore by wind action. The dune thus grows in height and width, the vegetation, in many cases, accommodating itself to a rising surface level.

At Port Fairy, Victoria, the advantages of marram grass for building up coast sand dunes, and in matting and binding together the sand, was strikingly illustrated some few years ago. During a storm and high tides the waves attacked one of these coast protection dunes and cut away the seaward face. After the storm had subsided, a face or small cliff of sand 8 ft. high was left standing, and it was seen that the whole depth was penetrated by a thick network of marram roots from top to bottom. A shifting dune, which would have been totally destroyed in a few hours, was, when fixed and matted together by the marram grass, a very efficient protection, and was only eroded by the waves with great difficulty. Another advantage of vegetation is that it tends to repair quickly any damage done by the sea during exceptional storms.

Fresh sand, blown in by the wind, is often collected and fixed by the marram grass, and the dune may thus, in course of time, be naturally restored to its normal condition.

The growth of vegetation on the sand dunes without doubt materially increases their resistance to erosion by wave action or other causes. Experience has shown that marram grass, when firmly established, effectively mats the sand together with a dense network of roots to a very considerable depth below the surface. Baron von Mueller states that marram grass will, by gradual upgrowth as the sand accumulates, form stems and roots, sanded into a depth of fully 100 ft.

The formation of a coast dune, and the fixing of it by vegetation, may directly prevent erosion, or the dune may act as a second line of defence, forming an embankment which, when properly overgrown, is capable of withstanding considerable onslaught by wave action during exceptionally high tides and gales. Although the formation of such a dune will not prevent some erosion, a dune of large dimensions is unlikely to be cut through completely by the sea during the limited time the high tides and gales last; and, furthermore, it is probable that at a very small expense the dune can again be built up by collecting blown sand.

The necessity for fixing and maintaining sand dunes is well illustrated by the numerous examples of erosion which has taken place where this important work has been neglected. The case of the Jutland coast is a typical example. Owing to general neglect of the dunes through lack of management and supervision, a breach was formed by the sea in 1825, and the Liimfjord, formerly a lake, was converted into a sound, and the northern part of Jutland into an island.

COAST PROTECTION DUNES.

The island of Ameland, off the north-west coast of Holland, may be cited as an example of both erosion of the coast owing to the neglect of the sand dunes, and also of the protection afforded against erosion by fixing them with vegetation. From time immemorial the island had been subjected to sea encroachment, the unfixed sand dunes being ineffective in preventing it. Now, however, the island is completely protected, the sand dunes having been fixed by the planting of grasses.*

At Barrow-in-Furness a considerable length of the coast (west side of Walney Island) is protected by sand dunes more or less covered with marram grass. Where the sand dunes exist no erosion has taken place in recent years, but the remaining part of the coast, on the contrary, has been considerably eroded.

On parts of the coast of British Guiana there is a belt of courida and mangrove trees which forms a natural protection against coast erosion. This protection has, in some parts, been almost ruined owing to the trees being cut down to allow of direct drainage into the sea; in fact, wherever this has been done, serious erosion of the coast has taken place.†

From the northernmost point of Jutland to the Elbe, continuously for a distance of nearly 300 miles, and in many places from the Elbe to the Atlantic borders of France and Spain, the coast is protected by a chain of sand banks and sand dunes. When maintained by Nature or man they are a very efficient protection against the sea. There are numerous places where Nature has not only built up a natural protecting barrier, but has provided for the preservation of the dunes themselves by clothing them with trees and shrubs.

By sand-binding grasses, with stems bending to the elements, and deep, wide roots gathering the sand together in a network of strong fibres, Holland largely holds the land she has wrested from the

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* *Vide* A. V. Horn, "Deutsche Banzeitung," 1887, p. 153.

† "Encyclopædia Britannica," vol. xii.

North Sea. Kohl states in one of his works ("Die Inseln u. Marschen Schleswig-Holsteins") that "the people here deal as gingerly with their dunes as if treading on eggs. He who is lucky enough to possess a mole hill or dune pets it affectionately, and spends his substance in cherishing and fattening it. That fair, fertile, rich province, the peninsula of Eiderstadt, in the South of Friesland, has, on the point towards the sea, only a tiny row of dunes—some 6 miles or so—but the people talk of their fringe of sandhills as if it were a border set with pearls. They look upon it as their best defence against Neptune. They have connected it with their system of dykes, and for years have kept sentries posted to protect it against wanton injury."

SAND PROTECTION DUNES IN FRONT OF CLIFFS.

Kessingland, near Lowestoft, furnishes us with an example of the influence of vegetation in preventing coast erosion. A considerable accumulation of blown sand has taken place in recent years in front of the house of Sir H. Rider Haggard, the well-known novelist. The cliffs at this part of the coast some years ago were subject to considerable erosion; now there is a remarkable accretion of blown sand at the foot of the cliffs, which, having been fixed by vegetation, forms an effective protecting barrier. The accumulation, which is about 12 ft. in depth, has taken place during the last twelve or fifteen years. Sir H. Rider Haggard, in giving evidence before the Royal Commission on Coast Erosion, stated that the increase in the sand, in his opinion, was directly due to the planting of marram grass on the slopes and at the foot of the cliffs.

At several other parts of the coast the erosion of cliffs has been completely stopped by the formation of sand dunes in front, which have become fixed by vegetation. At Winterton there are such sand dunes in front of the old sea cliff, and at Lowestoft dunes are also found in places at the base of the cliffs.

LIMITATION TO THE UTILITY OF PLANTING SAND DUNES FOR COAST PROTECTION.

It must not be supposed that man is entirely able to prevent coast erosion by the planting of sand dunes, or the formation of artificial dunes, and subsequent planting. Sand dune embankments when raised to a proper height and fixed by vegetation, are undoubtedly a very cheap and most useful method of preventing coast erosion. Such embankments, as have already been noted, will withstand the wave action during occasional storms, but they require constant attention, and it is often necessary immediately to repair any breach formed in the dunes during storms by collecting fresh wind-blown sand, and replanting where necessary.

In places where there is a tendency to steady erosion, it is sometimes essential to protect the sand dune embankment by a facing of a harder material, such as reinforced concrete, or the removal of the foreshore material and undermining of the dune by constructing groynes. The latter method is by far the best wherever possible.

While the utility of sand dune embankments, clothed by vegetation, in preventing erosion by wave action is limited, experience has shown that vegetation is entirely successful in preventing the inland movement of the dunes by wind action, and, at the same time, greatly retards the erosive action of the sea.

CHAPTER VI.

FORMATION OF SAND SPITS AND SAND ISLANDS.

The general tendency of the sea is to fill up indentations in the coastline, and to plane down headlands. On coasts where there is an ample supply of sand the sea, in conjunction with wind action, often builds sand spits or sand dune embankments in front of narrow bays or inlets.

Sand embankments and sand spits, enclosing bays and estuaries, are formed where there is a predominant drift in one direction. Commencing on the windward side of the coast, they gradually extend across the bay in the direction of the coastline on the other side. Where there is an abundant supply of sand, and also an enbayment in the coast, the sand is moved by the prevailing waves and currents in a more or less continuous manner; and if there is a comparatively narrow bay extending into the mainland, the sand, instead of being moved back into the re-entrant, is often built out in the form of a long sand spit. This spit in course of time may extend across the bay, and there are instances of river outfalls being diverted several miles from their original outlets.

The action of waves and currents alone is instrumental in building the sand spits cr embankments up to about the level of low water neap tides. After that level is reached the wind plays a very important part in their formation. At low tide the inshore winds blow the sand against the sea-constructed sand bank, and wind-formed dunes are then brought into existence. When the sand bar has been raised to high-water level of ordinary

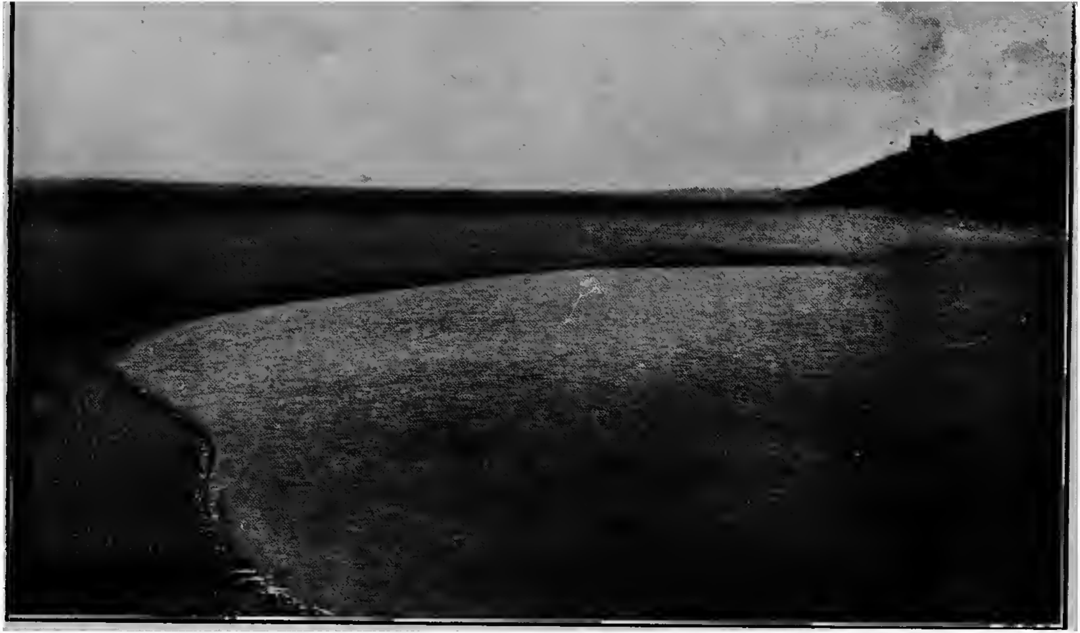

FIG. 15.—SAND EMBANKMENT CUTTING OFF LOE POOL FROM THE SEA.
(Geological Survey.)

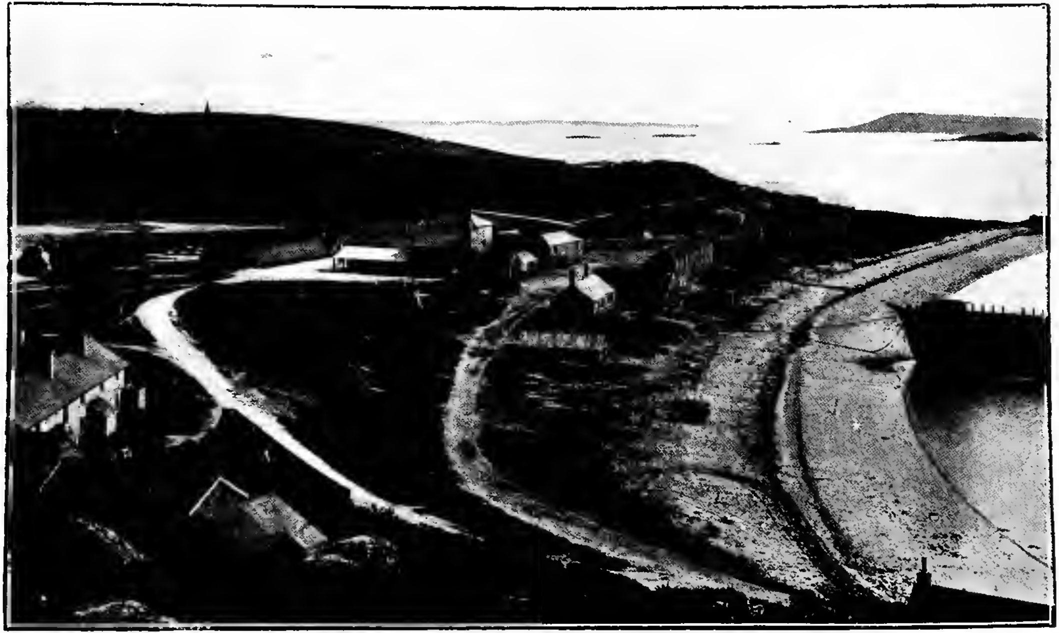

FIG. 16.—SAND EMBANKMENT AT TRESCO, SCILLY, WHICH KEEPS OUT THE SEA AT THE NORTH-WEST END OF THE GREAT POOL.
(Geological Survey)

tides vegetation actively assists the wind to build up and consolidate a sand dune.

Not only does the wind transport sand to the dune, but it also assists by helping to fill the sea bed or foreshore on the land side of the sand dune. The fine sand which is not retained by the vegetation is deposited on the land side. In places where little or no land water drains into the indentation or bay the sea and wind builds a continuous sand embankment right across it, and forms a salt-water pond. (Figs. 15 and 16.)

FORMATION OF SAND ISLANDS.

Where a considerable quantity of land water drains into a bay or indentation the land water at times of flood may break through a sand dune embankment in one or more places and allow the tide to enter. If rivers discharge into bays, the sea and wind are often unable to maintain a continuous bank, and consequently sand island dunes are formed. Sand spits during storms may also be broken through by the sea, and thus an island dune may be created. The "Bar" near Nairn is an example of a sand dune island, which at one time was probably a sand spit joined to the mainland near Buckie Loch. Very possibly the breaching of this sand spit was one of the causes of the formation of the Culbin Sands.

In Dublin Bay (Fig. 17) there are several dune islands.* On the Kingstown side of Dublin Harbour there was formerly a continuous sand dune spit from the Pembroke drainage sluice-house, extending half a mile in a south-westerly direction. Recently, however, it has been broken through by the sea in two places, and now constitutes at high tide three separate islands, while a fourth is now forming at the southern end. At low tide these dune islands are united to the mainland by a broad sandy foreshore.

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* "The Geology of the Country Round Dublin, Memoirs of Geological Survey, 1903."

At the north side of Dublin Harbour there is a long narrow ridge of sand dunes which was formerly an island, at an average distance of half a mile from the shore. It is now joined to the mainland by the North Bull harbour breakwater. Of late years this sand dune peninsula has grown out north-eastward very considerably, as a comparison of the 1837 and recent Ordnance maps clearly shows. At the back of the sand dunes, and under their shelter, a salt marsh has formed and is still increasing in area. If left undisturbed there is no doubt that the whole of the foreshore between the dune spit and the mainland would in course of time be formed into salt marsh, the surface of which would be gradually raised until it reached the level of high water of ordinary tides.

About 2,000 years ago, Mr. Wheeler states,* when the Roman engineers commenced reclamation works, Holland was described as an amphibious territory over which the sea had no defined limits, the rivers no constant beds, and the earth no solidity. The few inhabitants lived on the higher marsh lands or islands. In front of these tidal lands was a long chain of sand dune islands. The Roman engineers commenced the making of modern Holland by closing the gaps in the dunes and embanking the rivers. The existence of an almost continuous chain of sand dune islands enabled the Romans to reclaim at a small cost a large tract of land on which they used to grow corn to feed their large European armies. That reclaimed land formed the nucleus of what is now the kingdom of Holland, which covers 13,000 square miles of the most fertile land in Europe.

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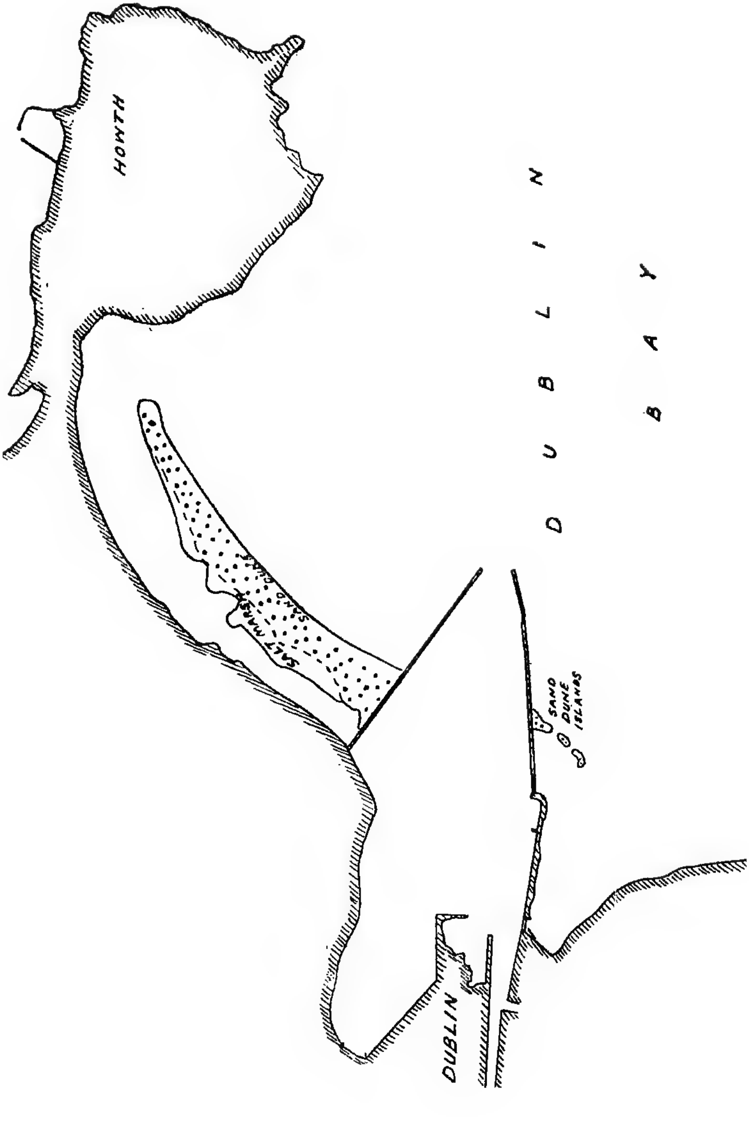
* "Minutes of Proceedings, Institution of Civil Engineers," vol. clxxxiv.


HOWTH
DUBLIN BAY
SAND DUNES
SALT MARSH
SAND DUNE ISLANDS
DUBLIN

On deeply indented coasts, and in front of bays, in America, a series of elongated sand dune islands, more or less enclosing lagoons, are found wherever the sea is shallow and the sea bed and foreshore are covered with sand.* Such sand bar islands are more characteristically exhibited on the eastern coast of America than on the coasts of other continents.

From Portsmouth to Cape Florida, and again along the Gulf of Mexico, from the western coast of Florida to the mouth of the Rio Grande, low sandy island embankments, separated from the mainland by lagoons, are a very conspicuous feature. From the waters of Chesapeake Bay to those of Biscayne Bay, a distance of about 700 miles, the sand dune embankments and islands are so continuous, and the lagoons which they shelter so connected, that one may journey in a small boat nearly all the way without being exposed to the open sea.

Where there is a predominant drift in one direction the sand dune island will often travel across the bay and eventually join on to the coast on the other side.

In the case of bays into which rivers discharge, the position of the entrance for the tidal waters and exit for the land waters is in many places constantly changing, as while the sea and wind are endeavouring to close the bay by a continuous sand dune embankment along which fresh supplies of sand can travel from one side of the bay to the other, the land waters are trying to find an exit. It is a continuous warfare, in which almost invariably neither side is entirely successful.

The mouths of rivers in some places have been diverted several miles along the coast. At Christchurch, Hampshire, the prevalent sand drift is in an easterly direction, and an embankment has been formed across the estuary of the river Avon. Its continued growth has caused the river outlet to be moved alongshore some distance in an easterly direction (Fig. 18). Some years ago, during a south-easterly gale, the sand spit was breached nearly opposite the original outlet of the river, and the sand spit was formed into a sand island, the river for a time flowing out at its old outlet. The fresh supplies of sand moved along from the westward have again formed a sand spit, and moved the river outlet eastward.*

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* Shaler. "Sea and Land."

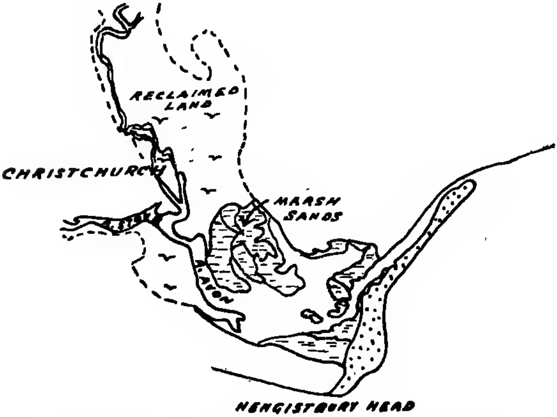

Fig. 18.—Sand Spit at Christchurch, Hampshire, which has Diverted the Outlet of the Rivers Avon and Stour.

Salt marshes have formed under the shelter of the sand spit.

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* Vol. ii., part ii., Minutes of Evidence before the Royal Commission on Coast Erosion.

*Exmouth "Warren."**—The estuary of the river Exe is partially closed by a sand embankment, locally known as the "Warren." This sand spit was formed by the prevalent eastward drift of the sand, and commenced to grow from the mainland on the west side of the estuary towards the mainland on the east or Exmouth side. The "Warren" consists of outer and inner sand dunes, which are divided by a shallow expanse of tidal water known as the Greenland Lake. If these natural sand embankments were breached by the sea, the anchorage known as the Warren Bight would be destroyed, and the Port of Exeter irreparably damaged.

The portion of the sand spit above high-water mark is about 2,600 yds. long, and extends from the western mainland, more than four-fifths of the total distance across the estuary, leaving a channel about 440 yds. wide for the tidal water to enter and for the river water to discharge. This channel forms the harbour entrance. The sand embankment is continued eastward in the form of a submerged sand bar, known as the Poole Sands, which is about 2,500 yds. long.

Since the natural formation of the "Warren," the supply of sand and grit from the westward has been almost entirely cut off. This is attributed to two causes; firstly, the formation of Longstone Point, which now acts as a natural groyne; and secondly, to sea defence works carried out by the Great Western Railway between the "Warren" and Dawlish for the protection of their railway line. These works consisted in the construction of a sea wall and groynes. In consequence of the littoral drift being greatly reduced, the "Warren" to some extent has been eroded, and it has also been moved bodily inland. The actual diminution in its size due to erosion has been somewhat confused with the bodily inland movement, which is quite another matter. The erosion which has taken place is partly attributable to the diminution in supply of littoral drift and partly due to the artificial removal of sand for ballasting. A comparison of the Ordnance Survey of 1809 with the recent surveys shows that, as a whole, rearrangement rather than destruction has taken place.

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* *Vide* Evidence of R. H. Worth before Royal Commission on Coast Erosion.

Partial breaches by the sea have taken place at different times, but there is no doubt some process of natural reconstruction was going on at the same time. Mr. R. H. Worth thinks it probable that a great part of the material constituting the "Warren" has been derived from the sandy estuary of the Exe.

In recent years works have been constructed to prevent the erosion of the sea face of the "Warren," but it does not appear that any work has been undertaken to prevent the bodily inland movement. This, as already mentioned, is an entirely different thing, and the work required to prevent the inland movement might have to be independent of any works required to protect erosion of the seaward face.

Heacham, Norfolk.—The outfall of the small river at Heacham has been diverted alongshore owing to the formation of a sand spit.* At one time the river had its outfall at right angles to the coast line, now it is nearly 2 miles further south, and the river is separated from the sea by a narrow sand embankment from 40 yds. to 50 yds. wide.

On the North German Coast there are several large bays into which rivers flow which are protected by sand spits. The Curische Haff Bay, into which the Niemen discharges, is sheltered from the Baltic Sea by a narrow sand embankment 55 miles long. The Frische Haff Bay, near Danzig, is also sheltered from the Baltic by a sand embankment 35 miles long.* In numerous other parts of the world there are notable examples of sand dune spits across bays in the coast into which large rivers discharge.

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* "Minutes of Proceedings, Institution of Civil Engineers," vol. clvi.

Where sand spits in the course of their growth come into contact with strong currents, their extremities are often turned, and make hooks which sometimes enclose considerable areas of water of sufficient depth to have value as harbours. Princetown Harbour, on Cape Cod, America, is an example of a harbour of this nature.

INLAND MOVEMENT OF SAND SPITS AND EMBANKMENTS.

After the formation of sand dune embankments or sand dune islands in line with the coast on either side, they are gradually moved inland if erosion of the adjoining coasts takes place. That is to say, they move inland at the same rate as the inland movement of high-water mark due to erosion of the coast on either side of the bay or indentation. On the southern shore of Martha's Vineyard, America, there are an extensive series of lagoons shut out from the sea by sand embankments, which have been moved inland at the rate of about 3 ft. per annum, in much the same way as an ordinary sand dune is moved.

FORMATION OF SALT MARSHES ON LAND SIDE OF SAND SPITS.

When sand spits or sand islands are formed across the mouth of bays or estuaries, and there is only a comparatively small inlet through which the tidal water can enter and the upland waters discharge, an accumulation of sand brought in by the tide, and silt brought down from the land, rapidly takes place over the bed of the sheltered bay or estuary. As the bottom is gradually raised, various species of marine plants commence to grow, and they increase the rate of deposit by arresting sediment which is in suspension in the water. The decayed vegetation and the remains of shellfish and other animals help to raise the surface level and to form a soil. Thus in time salt marshes are formed over which the sea only flows at high spring tides.

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* Wheeler, "The Sea Coast."

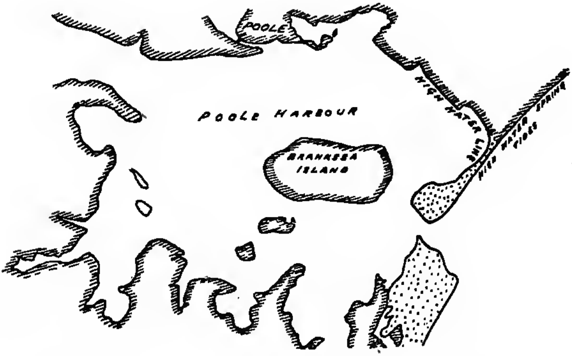

FIG. 19.—SAND SPIT DUNES PARTIALLY CLOSING THE ENTRANCE OF POOLE HARBOUR, DORSETSHIRE.

Enormous areas of salt marshes are thus in course of formation in various parts of the world. In the sandy bottom of the sea bed *Zostera marina* is the most important plant which assists in the raising of the surface level; when the level is raised above low water of ordinary spring tides, *Salicornia herbacea* and other plants take on the work begun by the Zosteras in deep water, and when the surface has been raised to the level of high water of neap tides, numerous varieties of salt marsh plants are able to thrive. Near Newburyport, Massachusetts, salt marshes having an area of 16,000 acres have thus been formed, and

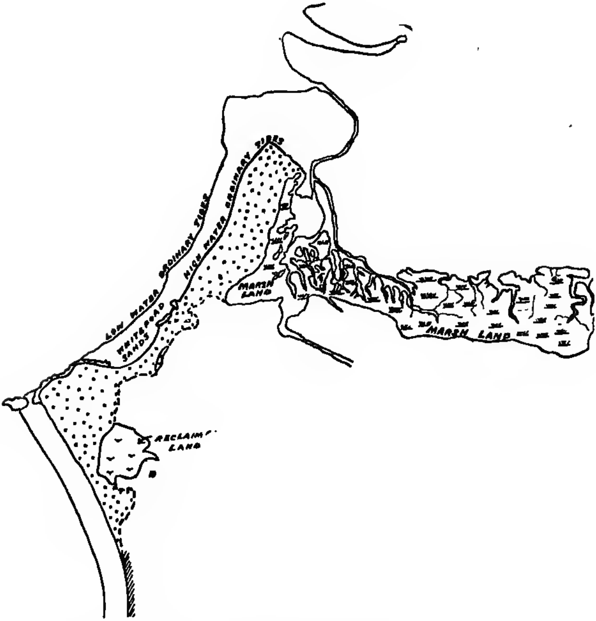

FIG. 20.—LLANRHIDIAN, CARMARTHEN BAY.

Marsh Land in course of formation under the shelter of a sand dune spit.

there are over 300,000 acres of marine marsh lands which will no doubt in the future make very fertile agriculture land.*

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* *Vide* Shaler, "Sea and Land, 1895."

RECLAMATION OF MARSH LAND PROTECTED BY SAND DUNE EMBANKMENTS.

When salt marshes which are only overflowed by the highest tides have been created in the rear of sand dune embankments the entire exclusion of the sea is often a simple and inexpensive matter. An earth bank or a timber embankment built across the entrance through which the high tides gain access to the marsh land, and the construction of a sluice to drain off the land water is all that is required. In many cases dunes have quickly been formed in front of the artificial embankment, and thus the whole bay or inlet is reclaimed and protected from inundation by a continuous sand dune embankment.

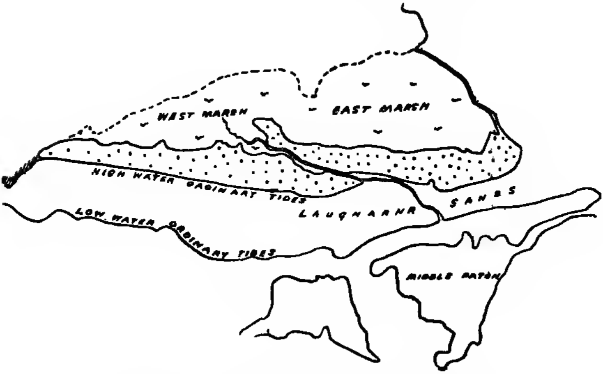

FIG. 21.—LAUGHARNE, CARMARTHEN.
Reclaimed Marsh Land Protected by Sand Dune Embankment.

Beween Winterton and Happisburgh there are about 56,000 acres of low-lying land in the valleys of the Bure, Yare and Waveney, which would be overflowed by the sea if it were not for the natural sand dune embankment which is mainly fixed by marram grass, and in some places is from 30 ft. to 50 ft. high. Going back to the Norman period, we find that the valleys of these rivers were an estuary of the sea, which then flowed up to Norwich. The sand bank here is about 9 miles long.

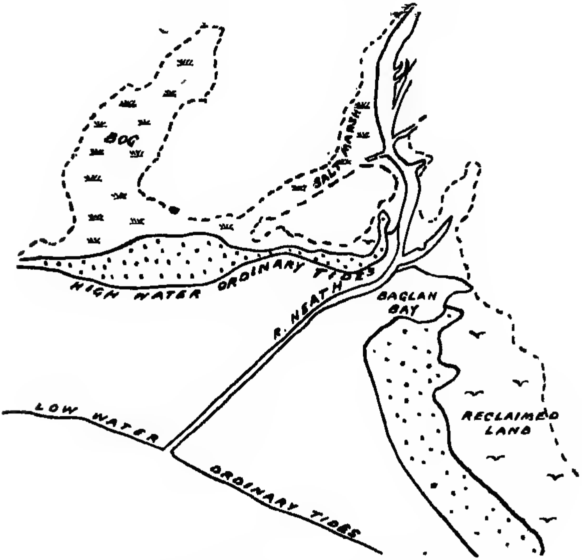

Fig. 22.—Swansea Bay.

Sand Dune Embankment Protecting Reclaimed Land and Salt Marshes.

Sometimes gaps in the dune embankment between Winterton and Waxham are made by the sea during storms, and then sand is blown through, inland, over the marsh in such a manner as to form buttresses; the breach is often closed up again in a few days by the collection of blown sand.

Sand dunes border a large portion of the coast in the Yarmouth and Lowestoft district.[*] They are more or less overgrown with vegetation, and form a natural embankment which protects about 40,000 acres of marsh land from inundation by the sea. This land in places is 2 ft. and 3 ft. below the level of high water of ordinary spring tides.

The Colman Estate, on the coast between Lowestoft and Gorleston, is protected at the southern end against sea encroachment by a sand dune embankment. Marram grass has been extensively planted, and its growth is everywhere encouraged. If this natural protection were washed away Gunton Denes would be overflowed by the sea. The whole coast line of East Lincolnshire, from Gibraltar Point to Donna Nook, north of Saltfleet, is bordered by a narrow range of sand dunes.[†]

Between Stickford and Wainfleet the average level of the ground is about 10 ft. above ordnance datum, but in some places it is not more than 7 ft. or 8 ft. This marsh land would also be covered by the sea at high tide if it were not for the sand dunes which border the coast line. The dunes in the widest parts are about a quarter of a mile across, but in most places they are very narrow, in parts being not more than 50 yds. or 60 yds. broad. In height the sand dunes vary from 20 ft. to 40 ft. above the level of the land inside which they protect. The sand is held together by a growth of marram grass (*Psamma arenaria*), with which coast barley (*Hordeum maritimum*) and wild wheat (*Triticum junceum*) are frequently associated. The sea buckthorn (*Hippophaë rham-*

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[*] Hewitt's Essay. "Encroachment of the German Ocean;" Phillips, "Memoire of W. Smith, LL.D.;" Blake, "Memoirs of the Geological Survey, 1890."

[†] A. J. Jukes-Brown, "Memoirs of the Geological Survey, 1887."

noides), and the blue bramble (*Rubus coesins*) are also abundant and assist in holding the sand.

Near Saltfleet a considerable area of land has been reclaimed by inducing the formation of a new line of sand dunes. In front of marshes at Margam, Oxwich Bay, Rhossili Bay, Llanrhidian Sands, Pendie Burrows, Penally, Tenby, Prestatyn, Kewstoke, Kenfig, and many other places around the coasts of Great Britain sand dunes also occur.

CHAPTER VII.

THE RECLAMATION OF TIDAL LANDS BY THE FORMATION OF SUCCESSIVE RIDGES OF SAND DUNES.

Where there is a wide expanse of sands at low tide the wind almost invariably transports inland from the foreshore a considerable quantity of the sand dried by the sun and wind. This sand is formed into ridges or dunes on the land margin.

If the dunes are not fixed, either naturally or by man, they are gradually moved inland, as previously explained, fresh dunes being formed from time to time, which take the places of those moved inland. In cases where the sand abstracted from the foreshore by the wind is equal to or less than the amount of sand transported on to the foreshore by sea action or littoral drift, and where the dune ridges become fixed by vegetation as soon as they are formed, then reclamation of tidal lands takes place. If the sand inblown by the wind from the foreshore is not replaced by sand moved in by the sea or littoral drift, then a steepening of the shore gradient necessarily follows, deep water is moved nearer inland, and the probability is that any gain of land owing to the formation and fixation of sand dunes will be only a temporary one.

COAST NEAR SOUTHPORT.*

In the neighbourhood of Southport, Lancashire, there are over 22 square miles of sand dunes, the accretion having taken place at a very rapid rate in the past hundred years. On this part of the coast the natural tendency for the sand hillocks to be formed and then fixed by grasses has to a considerable extent been assisted by man, who has caused the rapid formation of fresh dunes by erecting brushwood screens on the foreshore a short distance from and parallel to high-water line, and has assisted the fixation of the dunes by systematically planting thereon suitable sand-loving grasses.

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* Brodrick and Dickson, "British Association Handbook, 1903," Southport; Appendices to Reports of Royal Commission on Coast Erosion.

It is probable that none of the dunes in this district have been in existence for much more than 400 years. At Formby Point, where there is now a belt of sand dunes nearly 4 miles in width, no dunes are stated to have existed in 1690. Tradition says that the sand commenced blowing from a sand bank that had formed and driven the mouth of the Alt some distance southwards. At this time the natives were not acquainted with the advantages of planting the dunes to assist in fixing them, or of the use of brushwood fencing for preventing the sand from drifting inland, and as the natural growth of vegetation was not sufficient to prevent all inland movement of the dunes, a considerable tract of land was at this early stage overwhelmed by the advancing sand. At Formby the churchyard was at one time buried in sand, and was pulled down and rebuilt further inland about 1750. Gradually the people began to see the advantages of vegetation for fixing the dunes, and as a result of the more or less systematic planting not only was the inland drift stopped, but at the same time large areas of land were reclaimed from the sea.

Modern Southport is all built on sand dunes. Writing in 1809, one of Southport's first historians states that the "sandy desert" was slowly reclaimed by a hardy race, half fishermen and half farmers, who put up rude huts and planted patches of ground around them. In 1903 Southport had an estimated population of 64,000.

At the present time the coast between North Meols, north of Southport, and Bootle, for a distance of 16 miles, is fringed with a belt of sand dunes from 2 to 4 miles in width. The sand rests on the upper peat moss, and the dunes in some parts rise to a height of about 80 ft. above ordnance datum. Mr. H. Brodrick and Mr. E. Dickson state that the bases of the older—that is to say, the most easterly—dunes are stratified deposits, and contain fresh-water shells and also broken marine shells.

Rate of Accretion.—At Blundell Sands the average rate at which the high-water line has been moved seaward for the past fifty years is about 3½ ft. per annum. Measurements taken by Mr. T. Mellard Reade, F.G.S., showed that between 1866 and 1906 the sea had receded 138 ft. On this part of the coast the reclamation has been greatly assisted by the frontagers placing brushwood fencing to arrest the blown sand, and then fixing it by planting " starr " grass.

Between 1843 and 1906 about 9,000 acres of land on the Lancashire coast have been won from the sea, and a considerable portion of this was due to wind-blown sand. The British Association Handbook of Southport and District, issued in 1903, contains a geological sketch map (Fig. 24) by Mr. H. Brodrick. A comparison of the coast lines in 1841 and 1895 shows that from 3 miles north-east to 11 miles south-west of Southport nearly 2,000 acres of land was accreted. The average width of land gained on the 14 miles of coast referred to is about 20 ft. per annum for fifty-four years, or a gain of about 36 acres per annum. The largest gain appears to have taken place on the north-east side, where the high-water line has been

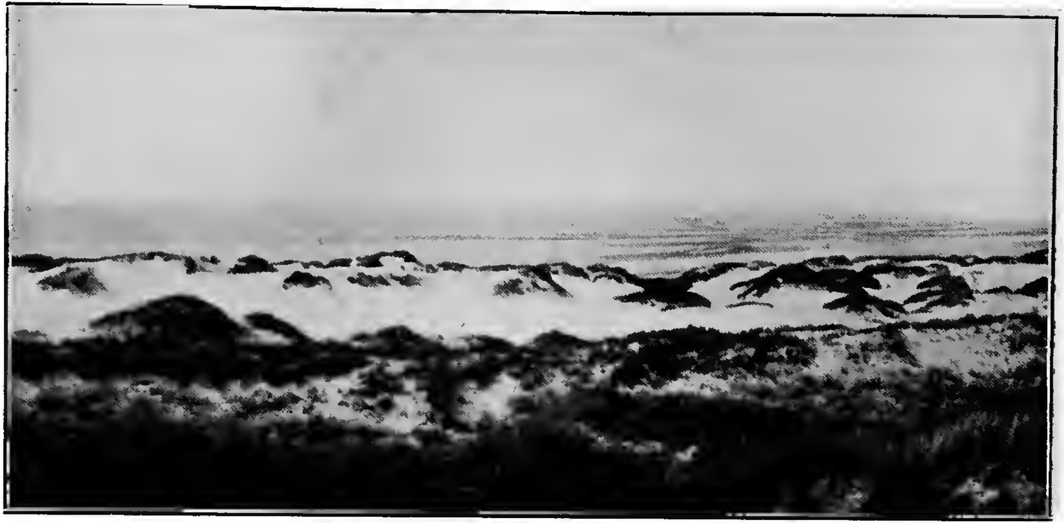

FIG. 23.—IRREGULAR-SHAPED SAND DUNES FORMED BY MARRAM GRASS COLLECTING SAND BLOWN IN FROM THE FORESHORE.

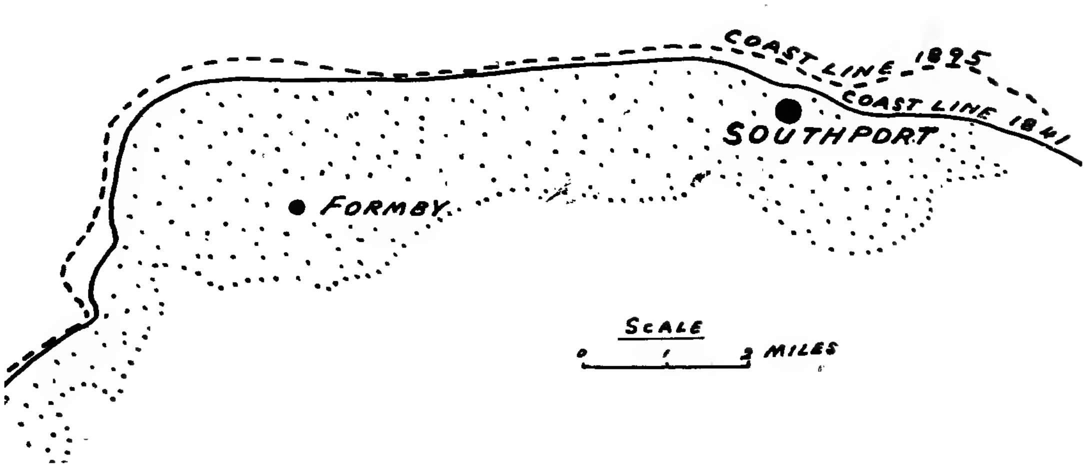

FIG. 24.—PLAN OF SAND DUNES IN SOUTHPORT DISTRICT.
(Brodrick.)

pushed seaward about 3,000 ft. in fifty-four years, or at the rate of about 60 ft. per annum.

Between 1884 and 1903 a belt of small dunes about 450 ft. in width formed on the sea side of the Birkdale Esplanade. The average width of land gained was nearly 24 ft. per annum. The increase at this part in recent years is stated to be greater than it is further down south, owing to the local conditions being more favourable for accretion, and to the fact that of late years the surface water which formerly was allowed to flow on to the shore has been diverted by drains, with the result that the foreshore sand is more rapidly dried by the sun and wind.

Utility of Brushwood Fencing for Assisting Natural Reclamation by Accumulation of Wind-blown Sand.—At Formby, Lancashire, Mr. C. S. Weld-Blundell, of Ince Blundell, has undertaken work for reclaiming tidal lands by the formation of successive rows of sand dunes. The method adopted is to set up lines of brushwood in the sandy shore just seaward of the existing dunes. Strips of frontage from 10 ft. to 20 ft. are taken at a time. For the brushwood fences willows are found to answer best. The trench in which the brushwood is planted is dug from 18 in. to 2 ft. deep. Behind these fences "starr" grass is planted to fix the blown sand which is gradually accumulated. For this reclamation work an experienced foreman, four labourers and a horse and cart are employed.

Mr. Weld-Blundell states* that in twenty years he has probably reclaimed along his shore a strip of land on the average about 300 ft. wide. To carry out this work successfully a long experience of the local conditions is necessary, which can only be gained by studying on the spot the action of the winds and tides. During exceptionally high tides the land gained is sometimes swept away again by the sea.

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* *Vide* **Appendix Third Report of Royal Commission on Coast Erosion and Reclamation.**

Opinions differ as to the origin of the sand on the Lancashire coast, and this has given rise to considerable controversy. Mr. T. Mellard Reade, in a memorandum prepared for the Royal Commission on Coast Erosion, gives the following interesting theory as to its origin: "If we turn to the chart of the Irish Sea by Captain Beechy, republished in a reduced form in Beardmore's 'Manual of Hydrology,' we may find a possible explanation. The tide of the Irish Sea, entering by the South Channel, meets the previous tide entering from the North Channel, creating a maximum rise of the tide at Fleetwood and Morecambe Bay. These tides bring with them sand which has a tendency to accumulate on the south-west Lancashire coast, producing the shallowing of the sea which exists. This sand has its origin in the destruction of the pre-existing Triassic rocks, and intermediately the glacial drift and some post-glacial beds. As a rule it consists of quartzose grains much rounded by attrition. The accumulation of this deposit on the foreshore gives free play to the winds,which sift the grains of sand from the small quantity of mud with which they are mixed."

SKEGNESS.

On the coast bordering this village there has been a considerable gain of land in the past 100 years, which is due to sand being blown inland. Mr. S. Coetmore Jones has made careful measurements of this accretion on the Earl of Scarborough's estate since the year 1849, with the aid of the Tithe Award plan of that date and the Ordnance Survey maps of 1904-5. The result shows that the average gain of land along the whole parish frontage has been at the rate of about 5½ ft. per annum, the maximum width of the accretion being 330 ft., and the minimum 45 ft. near the north end of the parish frontage.

The sea is shallow off Skegness, and there are a number of outlying banks of sand and gravel which are constantly being added to. In Mr. Jones' opinion most, if not all, of the sand which is accreting there is derived from these sand banks and from dunes north of Skegness which in recent years have been eroded.

In windy weather the surface of the sand banks at low water is rapidly dried, and large quantities of the sand are transported inland. Near high-water mark the sand is arrested by grasses and plants, and ridges of natural sand dunes from 20 ft. to 30 ft. high are formed by the assistance of the vegetation. The chief plants which thus build up and consolidate the sand dunes on this part of the coast are sea buckthorn (*Hippophaë rhamnoides*), marram grass (*Psamma arenaria*); there are also a small percentage of common elder, and in some places a few tea trees (*Lycium barbarum*). The spread of the vegetation which is so necessary for the formation of these natural dunes is to some extent assisted by blackbirds, thrushes, starlings and rooks, who feed on the buckthorn berries.

HOLKHAM, NORFOLK.

In a report made for the Royal Commission on Coast Erosion, Mr. Hugh Munro, forester for the Earl of Leicester's estate, said that near Holkham Gap accretion is taking place, owing to the action of marram grass and blowing sand. Near Overy also accretion is taking place due to the great quantities of blown sand coming in and being retained by a strong growth of marram grass. On parts of the coast of this estate faggot fences have been successfully used to assist the marram grass in building up the sand dunes.

SCOTLAND.

On the estate of The Macleod of Macleod, at the head of Loch Brittle, some natural reclamation has taken place in recent years owing to the accumulation of blown sand. The sand dunes are extending seaward at the rate of about 1 ft. per annum. Marram grass ("bent") is indigenous on this part of the coast, and grows up as soon as the sand is accumulated by the wind, and prevents further inland drift.*

In the parishes of Oldmachar and Belhelvie, Aberdeenshire, some natural accretion has also taken place in the last ten years, the inblown sand becoming fixed with marram grass. At St. Andrews some land at the links has been reclaimed from the sea by planting the inblown sand with sea lyme grass; in places the high-water line has been pushed seawards from 180 ft. to 250 ft.

Between Swilcan Burn and the mouth of the Eden, Scotland, a considerable quantity of sand in the past few years has travelled on to the coast from the sandy banks at the mouth of the Tay. This sand has formed into dunes which are fixed with sea lyme grass (*Elymus arenarius*). As the sand thus accumulated is constantly travelling on to the shore, and not blown in at the expense of the foreshore, accretion is taking place.

There are also numerous other places around the coasts of Great Britain where land has been won from the sea by the accumulation of wind-blown sand. At Beesands a village has been built on the sand accumulated under the cliffs. In Cornwall belts of sand dunes, locally termed "towans," have been formed on the coast margin.

***Appendix to vol. iii., Report of Royal Commission on Coast Erosion.**

There are several places in Wales where wide belts of sand dunes have been formed, and are locally known as "burrows." From Seaton Harbour to Maggis Burn, the Northumberland coast is bordered by sand dunes, and in the neighbourhood of Gloucester Lodge Farm the dunes have increased in area in recent years.

CHAPTER VIII.

THE FORMATION OF A LITTORAL OR COAST PROTECTION DUNE.

Before the work of fixing and reclaiming coast sand wastes can be undertaken, and the inland movement of a belt of bare sand dunes arrested, it is necessary to form on the sea coast, just landward of high-water mark of ordinary spring tides, a large artificial littoral dune to cut off fresh supplies of sand blown in from the foreshore. The formation of a littoral dune may also be necessary to prevent erosion of the coast, and in other places the existence of such a dune enables low-lying lands to be reclaimed from the sea.

Experience has shown that, broadly speaking, there are three ways by which man may form coast sand dunes—firstly, by planting just landward of high water a continuous line or belt of suitable sand-loving grasses and shrubs; secondly, by the construction of a solid wall or embankment of earth, sand, or other material; and thirdly, by the construction above high-water line of a continuous row, or rows, of openwork fencing made of boarding with a small space between each board, or of brushwood. The fencing made of boards, with spaces between, has the great advantage that the boards can be pulled up as the sand accumulates on both sides of the fencing.

Some of the most successful examples of the formation of littoral dunes are those where board fencing in the first place was used, and when a dune of a certain size had formed vegetation was also employed; suitable grasses which would adjust themselves to a slowly rising surface being planted in between the parallel lines of fencing.

Reference has previously been made to the successive ridges of sand dunes formed on the East Coast and elsewhere by vegetation. The final report of the Royal Commission on Coast Erosion refers to the use of grasses, such as marram grass (*Psamma arenaria*) and lyme grass (*Elymus arenarius*), above high-water mark for forming sand dunes. " The planting of these grasses," they state, " on sand above the reach of the waves encourages the formation of dunes, even at places where they did not formerly exist." The disadvantage of using vegetation only, is that it tends to form very irregular dunes, and in many cases does not collect and fix all the inblown sand, the result being the formation of successive ridges of blown sand rather than that of a continuous large dune.

If vegetation only is used it is also difficult to regulate the slopes of the dunes, and experience has shown that this is very desirable if the cost of maintenance is to be kept low.

Of the advantage of using vegetation in conjunction with paling fences there can be no two opinions. The use of the latter makes it possible to build up the dune, within certain limits, to the desired height and slopes, while the use of the former enables the sand surface to be efficiently fixed.

By inducing the wind to deposit the inblown sand in the form of a large littoral dune, in places where erosion is going on, or belts of bare sand dunes are being moved inland, or where it is possible to reclaim land, man is able to utilise the forces of Nature for the benefit and service of mankind.

FORMATION OF DUNES BY CONSTRUCTING SOLID EMBANKMENTS.

A sand embankment 3 or 4 miles long, thrown in 1610 across the Koegrass, a tide-washed flat between the Zuyder Zee and the North Sea, caused the formation of rows of dunes 1 mile in breadth, which excluded the sea therefrom. A similar sand bank or dyke, called the Zijperzeedijk, in the course of two centuries formed a belt of sand dunes almost as extensive.*

Between the Wash and the Humber an earth bank was constructed by the Romans to reclaim marsh land. The bank was not sufficiently high to prevent inundation at very high tides, but it caused the formation of a long range of sand dunes which covered up the earth bank. These dunes, where overgrown by vegetation, form a very efficient protection to the low-lying marsh land behind.

Some years ago the sea threatened to cut through the island of Ameland, the wind having blown away a lot of sand from the low flat which connected the two higher parts of the island. The construction of a groyne and sand embankment checked the erosion, and a chain of sand dunes rapidly formed.†

FORMATION OF LITTORAL DUNE BY THE CONSTRUCTION OF PALING FENCING.

The artificial littoral dune is usually formed from 100 ft. to 300 ft. landward of high-water line of spring tides. The first step to be taken is the erection of a continuous line of paling fencing. This may consist of boards about 6 ft. long, by 6 in. wide, by 1 in. thick, the bottom ends usually being pointed, and the planks driven about 3 ft. into the sand, and 1 in. space being left between the planks. Sand transported inland by the wind accumulates on both sides of the fencing, as previously explained. When the accumulation has risen to within a few inches of the top of the fencing they are pulled up about 3 ft. by means of levers, this process being repeated until a dune of the required height to prevent the inland drift of sand has been formed. Grandjean* puts this height at 10 metres, or about 33 ft. Fig. 25, taken from Schlick's "Manual of Forestry,"† shows successive stages in the construction of the dune.

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* D. T. Anstead, "Physical Geography."

† Marsh, "The Earth and Man."

It is important to regulate the slopes of the dune, and to arrange for it to assume a moderate

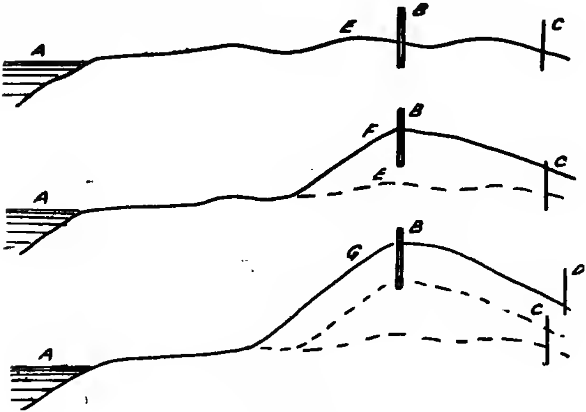

Fig. 25.

A—Sea level. B–Paling in three successive positions. C and D—Wattle fences. E—Original surface of littoral dune. F and G - Surface of littoral dune in two subsequent stages (the heights exaggerated).

slope, which is essential for its permanent maintenance.

Simultaneously, therefore, with the erection of the paling fencing, another fence should be erected at a suitable distance inland of the former. This prevents sand which has passed through the first line of fencing from being carried inland, and allows the slope to be regulated within certain limits. When the littoral dune has been built up to something approaching the desired height and shape, grasses, such as marram and lyme grass, which are able to grow upwards through a slowly rising sand surface, may be usefully planted.

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* La Dune Littorale. "Revue des Eaux et Forêts, 1887."

† "Schlick's Manual of Forestry," vol. iv.

Grandjean, in his paper on "Littoral Dunes," published in 1887, states that he considers B and C preferable to A (Fig. 26) for the cross-section of the littoral dune on account of their being much easier to maintain.

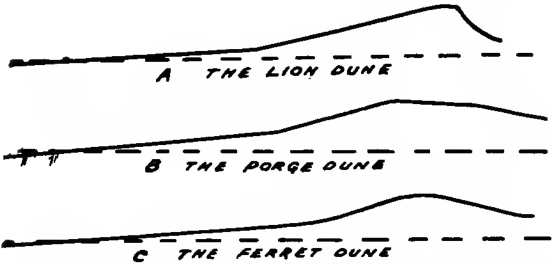

FIG. 26.—CROSS-SECTIONS OF LITTORAL DUNES.

PLANTING ON LITTORAL DUNE (SEA FACE).

As a rule it is useless to attempt to plant trees on the littoral dune, owing to the salt spray of the waves and the strong sea winds. The sand grasses most suitable for use on the sea face of the littoral dunes in Europe are:—

Marram grass (*Psamma arenaria*),* Baltic marram grass (*Psamma Baltica*), sea lyme grass

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* "Marram Grass." This name has been given in different places to several distinct kinds of grass which grow on sand dunes. It is also popularly known as "Klittelag" in Denmark, "Helm" in Holland, "Gourbet" in France. The marram grass has been scientifically designated as *Ammophila arundinacea*, *Arundo arenaria*, *Psamma arenaria*, *Psammophila arenaria*, and *Calamgrostis arenaria*. It is probably one of the most polyonymous vegetables found in English nomenclature. In some parts of England it is called "bent," "starr," "starr grass," and "sea bent," instead of marram grass.

(*Elymus arenarius*), sand sedge (*Carex arenaria*), sea couch grass (*Triticum junceum*).

Among other plants which, in Europe, will grow on the sea side of the dune are:—

Orache (*Atriplex arenaria*), seablite (*Suaeda maritima*), sea rocket (*Cakile maritima*), salt wort (*Salsola kali*), sea purslane (*Arenaria peploides*), sea poppy (*Glaucium luteum*).

PLANTING ON LITTORAL DUNE (LAND FACE).

Among the shrubs suitable for growing on the land side of the littoral dune are:—

Sand willow (*Salix repens*), sea buckthorn (*Hippophaë rhamnoides*), tea tree (*Lycium barbarum*), tamarisk (*Tamarix Anglica*).

FORMATION OF LITTORAL SAND DUNES IN FRANCE.*

The first steps taken to form the coast dune consist in the erection of a continuous line of paling, parallel to the shore line, and about 100 yds. landward of high-water mark of ordinary tides. The most satisfactory method of constructing the paling has been found to make it of boards about 1·60 metres (4 ft. 6 in.). long and from 2·54 centimetres (1 in.) thick. The ends of these boards, which are to go in the sand, are sharpened. A trench, about 15 in. deep, is then dug in the sand, and into this the paling boards are driven 7 in. or 8 in., so that when the trench is filled up they will stand just under 3 ft. out of the ground. A space about 1 in. wide is left between the boards.

When work on the French dunes was first commenced a solid wall was built instead of the paling fencing, but when it became buried it could not be raised, and was therefore expensive. A barrier made of a ridge of earth was also tried, and answered very well while it lasted. Solid walls or close-boarded fences do not collect the sand so well as paling fences owing to the eddies formed by the wind. A paling secured to strong string piers with spaces between was also tried, and did well until buried, but when built in sections required too much force to raise. Rows of stakes driven into the sand with brush woven in between, a little way up, and more added as the sand accumulated, have also been tried, the stakes being raised from time to time. This type of fencing answered fairly well.

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* F. B. Hough, "Report on Forestry, 1877," published by the Department of Agriculture, U.S.A.

Experience, however, showed that the paling fence made with separate boards driven in the sand with spaces between the boards was by far the best type of sand collector for use on the coast dune. With these paling fences a certain amount of sand passes through the spaces, and the sand is banked up evenly on both sides. This type of fence is not so liable to be blown over by gales as a solid fence, as the wind pressure is somewhat relieved by the openings, and only very oblique and strong winds ever blew down the palings, and then only in very exposed places, during exceptional gales.

When the sand has accumulated to the top of the paling fence, the boards are raised one at a time, and this process is repeated until the accumulation of sand has reached the desired height.. At first the method of raising the boards was to dig a trench at the side of the fence until the boards could be raised by hand, when they were planted anew. This method has the objection that it disturbs the sand, and renders it more liable to be eroded by the wind. In order to obviate this objection the boards were subsequently raised by a lever, a chain being placed round the plank, and the top of the next adjoining board used as a fulcrum. By raising them a little at a time and getting a new hold the boards were gradually raised to the required height. Afterwards this method was improved upon; a movable frame, made with a long lever mounted on runners (which could be slid along the fence to be raised), with pincers and chain, was found to work very well. The chain passed over an arc of a circle, near the head of the lever, and thus drew vertically. This apparatus is easily moved about, and can be worked by one man.

A lineal metre of paling fence costs from 2·5 to 3 francs, and if made of sapwood got from the inland pine plantations, and not creosoted, lasts about five years. The cost of maintaining the paling fencing is about half a franc per lineal metre, and the stake and brush fencing a third of a franc per annum.

The windward (seaward) slope assumes an angle of 7 to 12 deg., the landward slope being much steeper, and any angle up to the angle of repose of sand. Experience has shown that 7 deg. for the windward side and 22 deg. for the leeward side are the best slopes for the dunes. By altering the position of the paling fence, or putting a double row a few feet apart, the slope of the dune may, to a great extent, be regulated at will, but the regulation of the slope is generally accomplished by means of vegetation.

When the coast dune has been raised by means of the paling fences and vegetation to a height of about 12 metres, if necessary it is widened at the top by substituting for the paling fence quadruple rows of brush about 15 in. apart.

It has been found inadvisable to let the windward slope of the coast dune be steeper than 12 deg. If the angle is found to be greater than this, the paling is carried further back; for this to be done it is necessary first to widen the top as previously described.

Many French engineers make the leeward side of the coast dune as steep as possible—that is to say, they let the sand be at its inclination of repose. The stability and steepness of the land slope is sometimes secured by stakes interwoven with brush which have to be renewed from time to time.

When the paling has been fixed, tufts of marram grass (*Psamma arenaria*) are often planted in front of it, the width of the strip of sand planted being about eight times wider than the obstacle opposed. The tufts of marram are planted in quincunx order, and closer together near the paling. They collect the sand and adjust themselves to a rising surface level. The marram grass is planted in winter, and between the plants seeds of the marram grass and of *Triticum junceum*, *Artemisia*, *Kakile maritima*, *Salsola*, *Ephedra*, and other sand-loving plants are sown.

On the sea side of the dunes 121 marram plants, weighing 22 lb., each, and about 5¼ lb. of seeds are used to each acre of surface. The seeds are sown broadcast on the sand, and are not covered except the treading in resulting from the workmen passing to and fro.

A sand dune 12 metres high contains about 720 cubic metres of sand per lineal metre of dune. If the sand is coming in at the rate of 25 cubic metres a year, the increase in height of the dune will, when the height of a dune is 12 metres, be about 12 in. per annum. Experience has shown that it is very important to ascertain the rate of increase in the height of a dune, as the kind of trees, shrubs or grasses which may be successfully planted depends upon this factor. Grasses such as marram will thrive and adjust themselves to a fairly rapidly rising surface level; other plants cannot be successfully grown until the annual rise of surface level is much smaller. Tamarisk will grow well on the land face of the dunes when the rise of sand surface is not more than 1 ft. per annum.

During storms the wind sometimes makes breaches in the coast dune, and these are at once repaired by collecting fresh sand. For this purpose paling fences are sometimes set in lines obliquely to the main direction of the landward side.

The coast protection dune is indispensable if the inland dunes are to be reclaimed and profitably cultivated. It requires constant attention, and any breach caused by storms must immediately be repaired. The maintenance of the protection dune is on no account neglected, as otherwise the coast sands, in course of time, may encroach on the cultivated lands and overwhelm them.

FORMATION OF LITTORAL SAND DUNES IN CAPE COLONY.*

At the Gulchways, Port Elizabeth, it was necessary to form a coast protection dune before the work of reclaiming the inner dunes could be properly carried out. This work was undertaken by the Forest Department. A bush screen was constructed along the coast as close as possible to the high-tide level. As the sand piled up on both sides of the screen it was gradually raised, being always kept above the sand level. In 1894 the dune was about 25 ft. high; in 1901 it had a maximum height of 42 ft., and extended for over 2 miles along the coast. The sea face, the maximum slope of which is 28 deg., was planted with various grasses and shrubs, but they did not grow very well at first; patches of *Triticum junceum*, however, obtained a good hold on the sand. Pypgrass (*Ehrharta gigantea*) was tried, but was not found a success on the sea face, although it grows well on the leeward side. This would appear rather strange, as at Algoa Bay pypgrass grows almost into the sea.

Coast dunes, even when properly shaped and fixed by vegetation, require constant care and attention. They are liable to be damaged by exceptionally high tides and storms, in which case steps should at once be taken to collect fresh sand to fill the breach, and when this has been done, the surface of the newly accumulated sand should be properly planted.

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*Vide Reclamation of Drift Sands in Cape Colony, by C. H. D. Braine, Minutes of Proceedings, Institution of Civil Engineers, vol. cl.

Great damage may be done to sand dunes by burrowing animals, and whenever possible they should be exterminated. It is often advisable to take steps to exclude them from the dune area.

The Royal Commission on Coast Erosion, in their final report, state that "the preservation of sand dunes is most important along certain parts of the coast where they afford protection to low-lying areas behind them, and they should in these cases be maintained and fostered by the encouragement of the growth upon them of marram and other grasses which help to bind the sand together."

It appears that the planting of sea embankments was resorted to in very early times, for there is a curious entry in the Court of Rolls of the Manor of Selsey, under date September 28, 1584, forbidding the tenants to go upon "the sea wall while it is *green* to the Parsonage," under penalty of 3s. 4d.*

PLANTING ON LITTORAL DUNES.

To prevent the wind blowing sand inland from littoral dunes and to strengthen them against sea attack by binding with a network of roots, planting has been carried out in a number of places.

Carnarvon.—At the southern entrance of the Menai Straits the sand dunes at various times have been denuded by wind action. The Carnarvon Harbour Commissioners have undertaken work for the preservation of the dunes. Longitudinal and cross-wind screens have been erected to collect the sand, and marram grass has been planted.

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* G. A. Sinclair, "The Inroads of the Sea," *Scottish Historical Review*, July, 1910.

Pembrey Harbour, Carmarthen.—Some years ago there were signs that erosion on a considerable scale would take place unless remedial measures were promptly undertaken. Hedges of dead wood, therefore, were erected to collect blown sand, and the result has been very satisfactory. Marram grass and *Pinus maritima* have also been planted on the dunes.

St. Andrews.—The planting of sea lyme grass at the links (sand dunes) at St. Andrews, Scotland, has resulted in the blown sand being retained, and consequently a considerable raising in height of the dunes.

Sussex Coast.—Between Pagham Harbour and Bognor the coastline just landward of high-water mark in many places is bordered by a hedge of tamarisk, tea tree, boxthorn, and other shrubs; marram grass also grows. These trees are of use in consolidating the shore, which is thus better able to resist wave action during exceptional storms. The hedge is also effective in collecting inblown sand, which in time becomes overgrown with marram and other grasses.

Cape Cod.—The extremity of Cape Cod is largely made up of blown sand, upon which whortleberry bushes grow. Native pines are found in places on the land slopes of dunes, but in the past have almost been buried by sand, owing to the sea face of the dunes not being properly planted with vegetation. Land at Cape Cod has been devastated by the inland movement of the sand since Colonial days. In recent years steps have been taken to fix the dunes, and to protect the sea slopes by planting beach grass (*Calamgrostis arenaria*), and this has met with considerable success.

*Presque Island Peninsula, U.S.A.** — This peninsula forms the harbour of Erie, Pennsylvania, the harbour being a land-locked bay, 5 miles long, with a maximum width of 1½ miles. The peninsula itself is nothing but a long, low sand dune, about 6 miles long, with a maximum width of 1½ miles, to a minimum width of 300 ft. at the "Neck," which is 2 miles long, and joins the peninsula to the mainland.

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* *Vide* Report of Chief Engineer, U.S. Army, 1895. Part V.

Before the planting was undertaken there was considerable danger of the sea breaking through the narrow "Neck," the preservation of which was of vital importance to Erie Harbour. Erosion used to take place during storms from the west. In November, 1895, the waves washed over the "Neck" in several places, cutting shallow furrows in the sand bank. Another severe storm visited the coast there in December, 1895, but as the shore was then protected by ice no further damage was done.

The object of the planting undertaken by the United States Government engineer was to prevent further erosion of the narrow part of the peninsula. Trees were planted so that when growing they should catch the drifting sand, and thus increase the height and width of the "Neck," and also increase its resistance to erosion. At first the planting was undertaken on a moderate scale, so that the results could be watched before any extensive scheme was undertaken; 1,000 Carolina poplars, 200 Wisconsin willows, 200 yellow locusts, 200 Scotch pine trees, 3 bushels of blue grass seed, 2 bushels of orchard grass seed, 1 bushel of crimson clover seed, therefor, were purchased by contract. In addition to these, about 300 willow cuttings of a vigorous large growing species, 300 native willow cuttings, and 60 native poplar cuttings were obtained and set in the sand. Well rotted stable manure and leaf mould were placed in the holes before the trees were put in. The cuttings, however, were set in the bay shore without the sand being so enriched. Planting was done in April and May, by local labour, under the supervision of a Government inspector and a nurseryman.

The cost of planting was as follows:—

	£	s.	d.
Trees and seeds	32	11	0½
Manure and leaf mould ...	11	10	2½
Tools		12	3
Labour of planting	30	7	2½
Total	£75	0	8½

A subsequent examination of the trees and cuttings made at the end of a year showed most gratifying results. All the Carolina poplars were growing vigorcusly, except six, which had been destroyed by tramps. The yellow locusts were growing well, many of them having made 2 ft. of new growth. The Wisconsin willows were also flourishing. The Scotch pines were not doing so well, 52 out of 200 having died, and several more looked very sickly; many of them, however, were growing vigorously. The native poplars were still alive, but did not show much growth. The grass seed was sown too late in the season, and consequently was a failure.

Key West, America.—Owing to a vessel being wrecked on this coast in 1840, a quantity of cocoanuts were thrown upon the beach, where they sprouted and grew well, having spread as far north as Jupiter Inlet. Some of the trees which bear fruit have grown 40 ft. high, and afford an excellent protection to the sandy coast.

Baltic Coast.—On the shores of the Baltic marram grass is largely used on the coast sand dunes. It is planted in patches, so as to fill squares, 4 metres on the side, in "checker form."

Province Town, Massachusetts.—Many years ago the sea broke over the sand dune which connects Truro with Province Town, and swept a lot of the sand away. Beach grass was immediately planted, and the dune was again raised up to a sufficient height and breadth to protect the land.*

Belgium.—Coast sand dunes in Belgium are generally fixed by means of the sand reed (marram grass) and the *argoussier*. The marram grass is planted in tufts of 15 or 20 stems in quincunx order about 15 in. apart. March, April and November are found to be the best months in which to plant the grass.

The *argoussier* is a member of the *elæagnus* family; it is indigenous to Belgium, and is a shrub with silvery leaves. These plants, which grow well on the sand, are used for making hedges along the flanks of the dunes, and are efficient in stopping the drift of sand in exposed places.

Holland.—The existence of Holland depends largely on its dune barrier, which in many places is from 1 to 3 miles wide and 130 ft. high. A special system of planting rows of reeds on the dunes is frequently adopted. The reed screens catch the blowing sand, with the result that the dunes are raised in summer, and consequently give greater resistance to the heavy seas in winter. The screens are lifted up as the sand accumulates. Marram grass, locally known as "helm," is often planted between the wind screens. If it is scarce, fascines or thatching are often used to cover the sand. Where the sea faces of the dunes are eroded, leaving a more or less steep slope, they are sometimes levelled to form a slope of 1 in 2, and then planted.

Where there are high, steep crests to the dunes,

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* Dr. Dwight, "Travels."

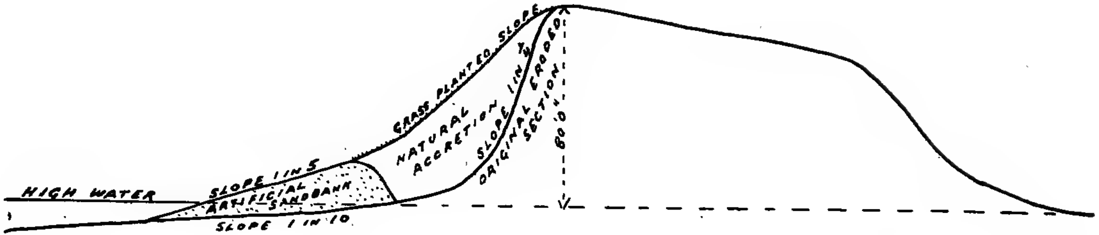

FIG. 27.—SAND DUNE, ISLAND OF SCHONWEN, HOLLAND.

Section showing erosion which took place during the winter months. In the summer the artificial sand bank was made at the foot of the dune. In course of time sand blown in by the wind accumulated behind and thus restored the dune to something like its original cross-section.

the grass is sometimes cut off; this allows the sand to be blown landward to strengthen the dunes at the back, or, during an offshore wind, to strengthen the sea face. Mr. de Blocq van Kuffeler thinks that the artificial improvements should be restricted to raising the foot of the dune by collecting and fixing the wind-blown sand.* For the latter purpose two or three coverings of rushes or straw a year are required, the successive following coverings extending a little farther seaward, the landward part of the toe dune being fixed by helm grass. Sand is lost during the winter, but it is won back again during the summer.

For preventing the permanent loss of sand from the foreshore it is found necessary in places to put groynes in front of the dunes, and in others the seaward sides are faced up with stone and concrete, and also with fascine work.

Blown sand at Callantsoog is collected by wisps of straw planted in the sand half a metre apart. Helm grass is not planted below 5 metres above high-water mark on the sea face of the dunes, as it is found to be killed by the storms in winter if planted below that level. Although the dunes protect private owners' as well as Government property, the whole cost of the work is borne by the Government.

On the island of Schouwen an eroded dune (Fig. 27) was built up again by forming a small sand bank at the foot and then accumulating sand behind by the planting of wisps of grass.†

THE MAINTENANCE OF SAND DUNE EMBANKMENTS.

Happisburgh to Winterton, Norfolk.‡—Between these two places, a distance of 12 miles, the low-lying land is protected by a sand dune embankment.

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* Minutes of Proceedings, Institution of Civil Engineers, vol. clxxxiv.

† Carey, Minutes of Proceedings, Institution of Civil Engineers, vol. clxxxiv.

‡ Mr. F. Horner, F.S.L., Evidence before the Royal Commission on Coast Erosion, and Appendices to First Report of the Commission.

The Sea Breach Commissioners are responsible for the protection of this part of the coast, and if the sand bank was not kept up the sea would flood about 56,000 acres of low-lying lands, chiefly in the valleys of the Bure and Yare and (on its Norfolk side) the Waveney.

Erosion has occurred, caused by the inland movement of the sand dunes, and also by the lowering of the foreshore, the dunes being then undermined.

Faggot fencing is employed for the purpose of collecting the blown sand. By this means the dunes, where necessary, are increased in width and height. In some places, where fairly wide gaps have been made in the dunes during storms, a new dune has been built up by means of faggot fences or screens. Where the coast crosses the old river estuary known as the Long Breach, at Horsey, such a dune has been built up.

In carrying out the faggot work the conditions prevailing at the time are carefully studied, and the arrangement of the faggots is so adapted or varied by the teachings of long and specialised experience as to secure the best results in sand accumulation. The number of faggots used in recent years exceeds 18,000 per annum, and sometimes has amounted to about 30,000.

Marram grass has been extensively planted by the commissioners, and grows more or less abundantly on the landward slopes of the dunes. It has been found very useful for arresting, impounding and consolidating the blowing sand. The grass is liable to be cut and otherwise destroyed, and is sometimes injured by rabbits. They have no power to take measures to protect it, and, in their opinion, it would be highly advantageous for them if they had. On the average the cost of maintaining the 9 miles of littoral dunes by faggoting, planting, &c., is about £400 per annum.

The sand dune embankments on this coast require constant attention and care, and it is necessary to collect sand and to repair any damage done by gales as soon as possible. It would appear that the seaward face of the dunes is not properly covered by vegetation, and that difficulty has been experienced in getting it to grow, owing to the keen winds. In the author's opinion this should be possible if the planting was done systematically and care was taken in choosing suitable plants.

Minsmere Level.—In the parishes of Leiston, Theberton, Dunwich, Westleton, and Middleton, in the county of Suffolk, about 1,600 acres of low-lying land is protected by a natural barrier of sand dunes. Behind the dunes an earth embankment, formed of alluvial marsh soil, was made by the Level Commissioners in the reign of George III., and this acts as a second line of defence in case the sand dunes are temporarily breached. Although the sea from time to time has damaged the natural sand dune barrier, high-water mark of ordinary spring tides has not advanced inland since 1810.

The chief work of the commissioners consists in maintaining the natural sand barrier defences, and for this purpose planting marram grass and "faggoting" are undertaken.

Faggoting.—The faggoting is used for building up the protection dune where necessary. This system was in use many years ago, but for the thirty years previous to 1901 was completely neglected, with the result that the protection dune in places was badly damaged by high tides. Since 1901 the faggoting has been systematically carried out, and the protection dune has increased both in height and width.

The method adopted is as follows: Rows of faggots are planted in the sand, with the thick end uppermost, and projecting from 18 in. to 2 ft. above the sand level. The first row is put in at the seaward bottom of the sand dune, and parallel with the shore. The next is put in about 6 ft. landward of the first, and behind this a third row. Each row of faggots is planted on a higher level than the one seaward of it. Beach and sand is piled up against the seaward row by the waves, and the wind-blown sand is collected by the other rows; the sand dune thus grows in width and height.

The faggoting is followed by the planting of marram grass, this binds the surface of the accreted sand, and helps the accretion. A dune thus built up and consolidated forms a very effective protection against the sea.

On the earth embankment at the back of the sand dune, marram grass, tamarisk, and buckthorn have been planted, and grow well. The roots of these plants are found to be valuable in solidifying the earth.

Sand le Mere, Yorkshire.—The Keyingham Drainage Act, passed in 1772, imposed an obligation on the commissioners to "repair, support, and maintain a certain dam, or rampart erected and built against the sea at a certain place called Sand le Mere, in the parish of Tunstall." The dam or rampart referred to consists of a sand bank or dune planted with marram grass. From time to time the commissioners have constructed thorn hedges or fences at the foot of the sand bank to collect the sand, which is freely blown inshore by east winds. They have also constructed a thorn fencing on the land side of the bank to hold loose sand. The length of the sand bank is 470 yds., and it has been maintained against the sea for 140 years without being breached. The cost of maintenance for labour and thorns since 1885 has been £108 13s. 9d., an average of £4 18s. 9d. per annum, or about 2½d. per yard per annum. The experience of the Commissioners goes to prove that the sand bank is a cheap and effective barrier to the sea, and that it can be maintained at a very slight cost, as the sand is thrown up by Nature with very little guidance and assistance.

Wareham, Wells and Holkham, Norfolk.—In this district considerable areas of low-lying marsh land on the Earl of Leicester's estate are protected from inundation by the sea by sand dune embankments. From time to time his lordship has carried out works for the protection of the sand embankments, faggoting and planting of marram grass being chiefly resorted to. On this coast there is a wide expanse of foreshore at low tide, and sand is blown in in considerable quantities. This sand is collected by faggot screens and vegetation.

In 1886 there were several very low gaps between Holkham and Overy, and faggots were procured and lines of them placed across the gaps, with side brackets at right angles to the main line. In a short time the faggots were nearly covered with blown sand, when the same process was gone through again on the higher or new levels, the old line of faggots always being avoided. In about three years sand dune embankments were formed 8 ft. to 10 ft. high, all interlaced with faggots. Marram grass was planted and has grown very strongly, and in 1906 the sand dunes near Overy boundary in many cases had doubled their original width. In eight years 39,000 faggots were planted on the Earl of Leicester's sea frontage at a cost of about £500.

The Lincolnshire Levels.—In the district under the jurisdiction of the Lincolnshire Court of Sewers there is a large area of low-lying marshes which would be covered by the sea at high-water spring tides but for a natural protecting sand dune barrier. The original defence of the district against the sea was a clay bank, but the level of this was insufficient to prevent the inroads of the sea. Fortunately, sand dunes have been formed naturally against the clay bank, and works are undertaken to maintain these natural defences. When necessary, rows of thorn faggots have been planted along the foot of the sand bank. The method of fixing them which is found to be most satisfactory is to insert them in a row at the seaward foot and parallel with the sand bank, so that when completed they have the appearance of a hedge with cross rows at intervals from the main row to the hill side. The effect is to intercept the dry wind-borne sand, and to accumulate a better toe to the sand bank. These thorn fences are also an advantage, inasmuch as they prevent or considerably decrease the foot traffic on the bank. Some of the fences are lost in heavy storms, but they will withstand considerable action of the sea, and lessen the damage which might occur.

In some places it has been found necessary to build breastworks. Vegetation, principally marram grass and sea buckthorn, grows plentifully on the south-west or sheltered side of the sand banks, but has not grown well on the sea side. In the author's opinion, however, the sea side could be covered by vegetation if a proper system of planting was introduced and the plants were carefully selected. Plants which will do well in some situations are quite unsuitable for others.

While desiring to show the great importance of maintaining coast sand dunes, and the utility of vegetation for this purpose, the author must also point out clearly that in places where steady erosion of the foreshore is taking place sand dunes alone cannot prevent the encroachment of the sea.

The ordinary state of equilibrium of a foreshore simply means that the supply of new material balances the loss. Anything disturbing this balance at once becomes evident by a gain or loss. If, from any cause or causes, there is a steady loss of sand from the foreshore in front of sand dunes due to sea action, then it is essential to take steps to prevent further loss, otherwise the dunes will in course of time inevitably be undermined.

GROYNING.

Generally speaking, groyning is the only satisfactory way of preventing the loss of foreshore material. The object of groyning is twofold—firstly, to arrest material transported by the water along the bottom; and, secondly, to build up the foreshore by causing the currents to deposit the fine material held in suspension. Until the introduction by the late Mr. E. Case of his system of groyning little or no attempt had been made in this country to build up the lower part of the foreshore by means of long, low groynes, which caused the currents to deposit on the foreshore material held in suspension.

While almost any obstruction will suffice to check the travel of shingle, the same is not true of sand. A groyne which would be eminently suitable for trapping shingle may be quite useless for collecting sand, and may even cause a serious scour to take place. Groynes should not be erected in front of sand dunes without expert advice. High groynes, which entirely stop the littoral or alongshore currents, are not suitable for sandy shores.

Speaking broadly, it may be said that the direction of sand drift is controlled by the prevailing currents, whether produced by wind or tide. The rougher the sea is, the greater is the amount of sand thrown into suspension, and therefore the greater is the chance of groynes to intercept it. The currents near the coast are usually approximately parallel to the shore line, the tendency being merely to transport material from one part of the coast to another, and so to circulate it round the coast.

In designing a system of groyning for collecting sand care must be taken not to divert the alongshore currents in a seaward or landward direction, either by making them too high or by putting them other than at right angles to the main direction of the flow of the currents. Where groynes are constructed in front of sand dunes care must be taken not to introduce any new factor which may render them useless. For instance, there are places where a very good type of groyne has been constructed, but where the planking has not been carried sufficiently deep into the foreshore, and as a result the bottom edge of the planking, after a short time, was, for a considerable length of shore, above the foreshore level. The currents in such a case flow along the shore and strike the groyne; the sectional area through which they have to pass being reduced by the planking, they are diverted both over and under the groyne at a higher velocity than the normal, with the result that the shore is scoured away directly under the planking, and more harm than good is done. It is therefore of the utmost importance that there should be no under-run beneath groynes on sandy shores.

We sometimes see it stated that it is useless to erect groynes upon a foreshore where there is no fresh material to collect, but it must be kept in mind that the function of a groyne is not solely to collect material. They have a very beneficial action in front of some sand dunes in checking erosion and holding the material already upon the foreshore, which would otherwise be carried away..

HEIGHT OF GROYNES.

In places where groynes are put up more than about 3 ft. in height irregular accumulation, if any, takes place. While the shore on the windward side of high groynes may be built up, actual denudation often takes place on the leeside. It is very important on sandy shores to build the groynes low in the first place, and only to raise them as the shore surface is built up. In this way a groyne which is technically a "low" one may eventually, as the shore is raised, become a very high one when measured from its own foundations; but it must never be high above the foreshore surface.

On a sandy shore, low groynes, without completely intercepting the littoral currents, slow down the lower layers of water sufficiently to throw the sand out of suspension, the upper layers of the current being permitted to flow over the tops of the groynes, bearing the sand along and gradually losing it as the grains sink into the lower and more slowly moving parts of the current nearer the shore surface.

DIRECTION OF GROYNES.

Some engineers hold that angle groynes—that is, groynes directed towards or away from the side from which the prevalent wind comes—are more efficient than right-angle groynes. On the South Coast the author has come across several instances where groynes built across the shingle in a south-easterly direction have been very successful in collecting and retaining shingle, but in every case which has come under his notice such angle groynes have caused a serious scour when carried across the sand below the shingle, and he has never once come across an angle groyne which has been a success in collecting sand.

The efficiency of a groyne depends, to some extent, on its capability of intercepting drift—that is to say, it depends partly upon its effective length—*i.e.*, the distance to which it extends across the littoral currents. In the case of alongshore currents transporting sand, any divergence from the right angle means a reduction in efficiency for a given length of groyne.

When waves strike the shore in a slanting direction, the water flowing down the shore from the back wash, and any land water is intercepted by the angle groyne, a serious current is produced, located on one side of the groyne. Instead of having the water spread out in a thin layer over the shore, it is concentrated alongside the groyne, and produces a channel down which sand is swept seawards.

Another objection to angle groynes on a sandy shore is that more surface is exposed to the wave stroke, and, consequently, there is a greater liability to scour due to the rebound of the waves, and also a greater liability to damage. In other words, groynes slanting away from the prevalent wind are more expensive to construct and to maintain.

DISTANCE APART OF GROYNES.

At the present time engineers are guided by rule of thumb in deciding the distance apart of groynes. The distance apart found by experience to answer best is generally about the distance between high and low water lines. If placed too close together groynes on sandy shores may actually do more harm than good. When a current strikes a groyne which does not completely intercept it a series of eddies is set up, the distance to which they extend depending on the depth of water and the velocity of the current. If another groyne is met by the water before the disturbance has died away the result is to reduce the chances of deposition.

LENGTH OF GROYNES.

In the author's opinion groynes should be built from above high-water line as far seawards as possible; the greater the length the greater the efficiency. In some cases it is necessary to extend the groynes beyond low water. It is very common to find a sand bar just seaward of low water, and by extending groynes well into such a bar it is generally possible to move it inland, the sand, in course of time, being levelled up between the groynes.

MATERIALS FOR CONSTRUCTING GROYNES.

In choosing a material for constructing groynes on a sandy shore, durability and high specific gravity are the two principal qualities to be sought.

Durability is affected by ordinary decay, attrition by moving sand, chemical action and exposure to changes of temperature, direct attack by the sea itself, and destructive action of the sea worms *Teredo navalis* and *Limnoria terebrans.*

The chief materials used for constructing groynes on sandy shores are timber, concrete, reinforced concrete and fascine mattresses weighted with stone.

The disadvantages of timber are its low specific gravity, liability to decay, and attack by sea worms. The author has come across cases of long, low timber groynes destroyed by the latter in the course of three or four years. The *Limnoria* confines its ravages to the range of the tides, and the *Teredo* commences its work of destruction above high water of ordinary tides, and carries it on below low-water line.

Brushwood mattresses weighted with stones have a comparatively short life. Referring to the failure of a jetty made of brushwood mattresses weighted with stone, and constructed at Galveston, U.S.A., in 1883, Mr. O. Chanute, M.AM.SOC.C.E., says*: "The settlement was caused partly by compression of the brush and stone, and partly by the action of the *Teredo navalis*, which is exceedingly active in the southern waters, and eats up even the smallest twigs if it can get access to them."

Mr. G. B. Wheeler Jackson, in a paper on "Engineering Works in Holland," says that the fascine mattresses used in Holland are easily kept in repair, but require constant attention, and will last about a year if only exposed to the action of the sea.

Groynes made of masonry or concrete blocks are almost prohibitive, owing to their enormous cost, and do not admit of that flexibility which is so desirable in a groyne, and are difficult to raise or lower. Timber, while cheap, is not very durable, and its light weight is a disadvantage. For the construction of groynes on a sandy shore reinforced concrete has greater advantages and fewer disadvantages than any other material. It combines the advantages of concrete and timber, it has a high specific gravity, is not prohibitively expensive, and is eminently suitable to withstand the rough usage of the waves. Groynes made of piles and slabs of this material can be readily built up as the shore accumulates.

CASE GROYNES.

This system of groyning, which has been much adopted in this country, was very fully described by the late Mr. E. Case in his paper before the British Association in 1899, and has been frequently referred to in numerous papers and newspaper articles.

Briefly, the system consisted in erecting long, low adjustable groynes extending across the whole foreshore and often beyond low-water line. The tops of the groynes conformed to the natural curvature of the shore. The planking was kept to a uniform height of about 18 in. to 2 ft. above the sand surface, and gradually raised as the shore accumulated.

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* "Transactions," American Society Civil Engineers, vol. xv.

The method of construction usually adopted was to form piles of two pieces of timber bolted together, with a distance piece at top and bottom. These were fixed in the foreshore at intervals of 7 ft. 6 in., their lower ends being embedded in concrete, rammed into holes dug in the shore. Planks were fixed in the slots formed by the two halves of the piles, and gradually added to as the sand accumulated. Given a hard substratum underlying the sand, this method of fixing the piles is without doubt a very good one, but, owing to its being applied to shores consisting only of sand within a reasonable depth, some cases of failure are on record.

In 1897 considerable erosion of the foreshore took place in front of the sand dunes, and the New Romney Level Commission of Sewers called in the late Mr. E. Case to advise them as to the best means of preventing the erosion. On his advice eleven low groynes on the "Case" system were constructed. Since then thirteen more low timber groynes have been constructed, and between 1902 and 1909 a number of small faggot groynes have been put in between the "Case" groynes. The low groynes have done a lot of good, and have had the effect of raising the sand at the foot of the dunes.

OWENS-CASE REINFORCED CONCRETE GROYNES.

These groynes consist of reinforced concrete piles of H section, fixed in the shore at suitable intervals apart, reinforced concrete slabs being fitted in the spaces between the piles. The piles and slabs can be made to any required size or strength, according to local conditions, and the planking slabs can be added as the shore accumulates. Groynes on this system, designed by Dr. J. S. Owens and the author, and reinforced on the Hennebique system, have been constructed in several places, and have been very successful. The cost of low groynes on this system on a sandy shore varies from 8s. to 15s. per foot-run.

GROYNES IN HELIGOLAND.

M. Franzius designed a system of groyning which has been carried out on the foreshore in front of "Dune" Island, Heligoland. Eight fascine groynes have been put up, and they extend to beyond low-water line. They are from 32·8 to 39·36 ft. wide, and 3·28 ft. high in the centre, sloping to the shore on either side. Between high and low water lines the fascines are fixed to the shore by Bucking's system of anchors, screwed into the ground. Below low-water line the fascine mattresses were constructed on land, floated into position, and then sunk with stone ballast. A number of transverse fascine constructions join the principal groynes. The groynes are stated to have been a success, and to have resulted in the low-water mark being driven seaward more than 190 ft. The works do not appear to have been down sufficiently long to enable any definite opinion to be expressed as to their durability.

GROYNES IN HOLLAND.

In front of the dunes at Scheveningen seven groynes have been built. They are made of brushwood fascines covered with large stones, with basalt pitching between rows of piles. Each groyne is about 220 metres in length, and about 10 metres wide.

Between 1790 and 1896 groynes to protect the sand dunes were constructed along the whole coast line between Scheveningen and the Hook of Holland, at a cost of about 6,000,000 florins. At first the groynes were made about 230 metres long, and were placed at an average distance apart of about 500 metres. Since 1896 many of the groynes have been lengthened about 100 metres seaward, and as a result the low-water line has been pushed back at the rate of 1½ metres per annum, the inclination of the shore being at the same time flattened until it was 1 in 40.

About fourteen years ago the Dutch Government found it necessary to construct a series of groynes to protect the foreshore in front of the sand dunes at Callantsoog.* The groynes were of the usual type in Holland, fascine mattresses being first laid and then covered with bricks capped with basalt. The gradient of the groynes is 1 in 40, and the older ones were about 250 metres long, and 300 metres apart, and cost 60,000 florins each (£5,000). The more recently constructed groynes are 150 metres long, 200 metres apart, and cost 37,000 florins (£3,100).

Since 1899 groyning works on a very extensive scale have been constructed in front of the sand dunes between Helder and Petten on the west coast of North Holland. Between 1899 and 1911 twenty-eight groynes were completed, and at the latter date thirty-six remained to be built. The groynes have been made about 490 ft. long, and spaced 656 ft. apart, at right angles to the shore line. Most of them have been constructed with fascines, and basalt from the Rhine, and cost about £3,000 each, exclusive of the cost of a necessary railway on the sand dunes along the coast. The sea head of the groynes and the first seaward 65 ft. may be taken as costing about

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* Appendix lxiii., Third Report Royal Commission on Coast Erosion.

£1,000, the middle part, 312 ft. long, £1,650, and the landward part, 115 ft. long, £350. Recently, the question of using reinforced concrete has been carefully considered. For the parts of the groyne built on the sea-bed below low-water line, which are much more expensive than the part built on the foreshore, Mr. A. T. de Groot, of Alkmaar, considers that fascines must be used to prevent the sand underneath from being washed out and carried away by the waves and currents. Fascine mattresses, when used in places where the sea bed is of the nature of quicksand, have the advantage of being elastic and accommodating themselves to all changes in the sandy bottom. For three groynes constructed during 1910 Mr. de Groot used reinforced concrete for the landward 174 ft., the method of construction being shown in

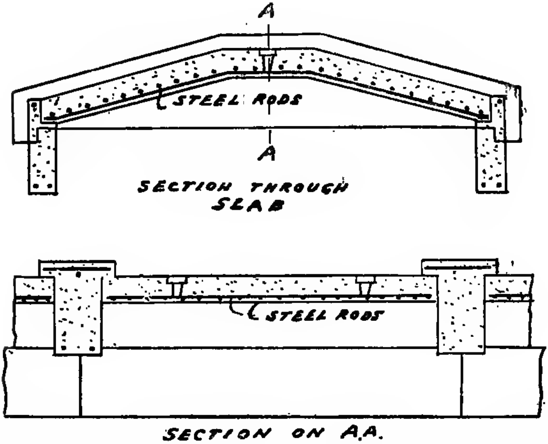

FIG. 28.—SECTIONS OF REINFORCED-CONCRETE GROYNE BETWEEN HELDER AND PETTEN, HOLLAND.

Fig. 28.* The groyne was made 16 ft. 5 in. wide, the difference in height between the top and the edges being 20 in. The longitudinal slope was made the same as the slope of the shore, or about 1 in 45. Each section of the groyne was made 13 ft. 2 in. long, and was formed by first erecting the side beams in trenches. The shore material between the beams was then heaped in a round-topped form, and covered with straw or rushes. Afterwards the concrete slabs, 11 ft. 6 in. long, reinforced with steel bars, were made in between cross screens. When the concrete had set, the space between the two slabs was filled with a cross beam, which had a framed flange, with a breadth of 31 in., and a height of 6 in. above the slab. The cross beam was reinforced with five steel bars, one being bent round the bar of the beam in the direction of the length of the groyne; and, in addition, the cross beams bound together the side beams as shown. To prevent scouring out and subsidence of the groyne, the sandy foreshore adjoining the groyne was protected with fascines and basalt over a width of 8 ft. 2 in. This type of groyne costs about £1 2s. 8d. per foot run.

Reinforced concrete groynes, designed by Mr. Van Kuffeler, have been constructed on the landward part of the foreshore in front of sand dunes in Holland. The groynes consist of two reinforced concrete walls, which form the sides. These walls are united at the top by a beam which is connected together at intervals. The space between the walls is divided into squares. For this purpose the slabs were divided in the middle, the two halves being kept together by a frame. Steps, in some cases, have been formed in the slabs, as an experiment, with the object of breaking the water running off the groyne, and diminishing the scour on the foreshore. In Vlieland it is found desirable to be able to vary the height of the groynes. At the joints, therefore, reinforced concrete piles (Fig. 29), with grooves, were placed; between these, boards could be placed, and the groyne thus raised 2 ft. if desired.*

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* Minutes of Proceedings, Institution of Civil Engineers, vol. clxxxiv.

A reinforced concrete groyne has been constructed at the island of Schouwen on the de Muralt system. This groyne consists of concrete slabs and concrete frames. The cost was £1 11s. 5d. per lineal foot, the corresponding estimate for a basalt pitched groyne being £3 12s. per lineal foot.

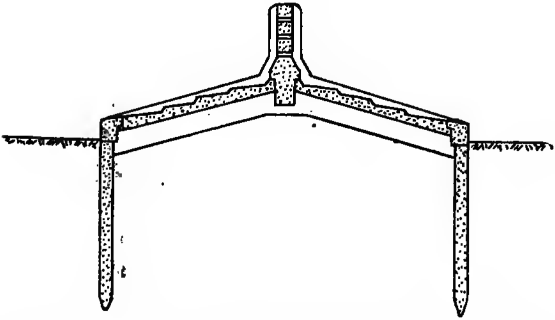

FIG. 29.—SECTION OF REINFORCED-CONCRETE GROYNES, VLIELAND, HOLLAND.

GROYNES IN BELGIUM.

On the north-east side of Breedene, in front of the sand dunes, there are a series of small stake and wattle groynes constructed with fascines, made with mattresses of willow twigs.† An edging of basalt blocks is placed between the outer fascines. The groynes are 36 metres long, 6½ metres wide, and 1 metre in height, and each of them costs about £75. This part of the coast is not subject to heavy seas, and the chief use of the groynes is to collect the wind-blown sand; they only last about five years, and the light type of construction would be useless on a shore exposed to much wave action or shingle travel.

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* Minutes of Proceedings, Institution of Civil Engineers, vol. clxxxvi.
† Appendix lxiii., Third Report Royal Commission on Coast Erosion.

The sand dunes at Wenduyne are protected in one place by a groyne constructed of bricks over a backing of 8 in. of concrete, the cost of the work being about 6s. 8d. per square metre. In the first place it was constructed with concrete, but was damaged by a storm. In its amended form it is not considered a success, and it is not proposed to construct any more groynes of this type. There are also on this part of the coast some short groynes constructed of fascines with a covering of basalt blocks and a row of ferro-concrete posts.

CHAPTER IX.

PROTECTIVE WORKS ON THE SEA FACE OF LITTORAL DUNES.

In exposed situations where the sea face of the littoral dune is subject to erosion by wind action, and by the sea during storms, and where it is difficult to get suitable vegetation to grow, an artificial facing of fascines, concrete or other material is sometimes built.

The construction of an artificial facing on the sea side of the littoral dune can only act as a passive defence, and will in no way prevent the foreshore in front from being scoured away. Should there be a tendency for erosion of the foreshore, groyning works must be constructed in front of the facing, otherwise the latter will, in course of time, inevitably be undermined.

EXMOUTH.

At Exmouth Warren, a natural sand embankment across the estuary of the Exe, works to prevent the erosion of the seaward face of the embankment have recently been undertaken. A bank of large blocks of stone has been formed, and backed up with material well calculated to resist the wash of the waves. Groynes have also been constructed.

NEW ROMNEY, KENT.

For the protection of the foot of the dunes the New Romney Level Commission of Sewers, since 1907, have placed a row of faggots for some distance along the coast. In some places a single row has been planted in the sand, and in others a double row with clay in between.

BELGIUM.

On the north-east of Breedene a long stretch of dune protection work has been carried out.* It consists of a sloping revetment of ferro-concrete with a rounded top, and rests solely on the sand. On this part of the coast there is a wide foreshore with shallow water at high tide, the coast being protected by outlying sandbanks. It is only at high tides during gales that the sea breaks against the ferro-concrete dune facing. The revetment is constructed in bays of 15 metres, with joints filled with asphalt between each bay to allow for the expansion and contraction of the ferro-concrete.

Sand dunes border the parts of the Belgium coast known as Maria-Kerke and Middle-Kerke. At Maria-Kerke the sea face of the dunes is protected by a sea wall on top of which is a roadway. Here the sea wall or pitching is built of random masonry. The Middle-Kerke sea wall is built of brickwork with sheet piling at the foot of the slope. In 1899 a series of Case groynes were constructed in front of these walls.

HOLLAND.

At Arendsduin, near Scheveningen, the sea face of the sand dunes is protected by a covering of clay about 1 metre thick. The dune sand face is first made to an even batter, lumps being cut off where necessary, and other places being filled in with sand. At Scheveningen itself the Municipality of The Hague and the Hoogheemraadschap Delfland (Commission of Levels) have constructed about 3 kilometres of sea wall to protect the dunes. The wall is made of concrete covered with basalt.

In the neighbourhood of Flushing the town authorities have constructed a ferro-concrete facing to the littoral sand dune. The work is above ordinary high-tide level. From their inspection of the work, the committee of the Royal Commission on Coast Erosion came to the conclusion that it would probably be destroyed if it were subject to the action of heavy seas.*

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* Appendix No. lxiii., Third Report Royal Commission on Coast Erosion.

At Westkapelle, where the sand dunes do not form an adequate protection, an embankment (dyke) has been formed. The upper portion of this dyke consists of a very slight slope of sand with grass growing on it. Lower down, the slope is covered with straw matting, locally termed "krammat," which is fixed with pegs, and rests on a clay bed about 3 ft. thick. Seaward of the matting comes the chief protective work, which consists of basalt blocks resting on a clay bed with a matting of straw between the clay and the basalt. The average gradient of the lower slope is 1 in 7. Experience shows that the annual cost of maintaining the straw matting is about 1s. for 5 square metres, and in future it is proposed to use concrete slabs in its place, as being much more permanent.

On the slope of the lower part of the embankment there are five rows of creosoted oak piles standing about 1½ metres above the surface of the basalt pitching, and about 1 ft. apart, to act as wave-breakers.

At Domburg a reinforced-concrete revetment has recently been constructed in front of the dunes at the Strand Hotel frontage. The reinforced concrete is laid on the sand slope, and the toe is protected by a concrete vertical wall 1 metre in height, faced with rough timber piling. The top of the work is 14 ft. above high water, and the whole of it is above ordinary high-tide level. The cost of 125 metres of the protection was about £1,000. In the winter months sand is washed away from the toe wall, and in 1908 the revetment, in consequence, slightly subsided.

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* Appendix No. lxiii., Third Report Royal Commission on Coast Erosion.

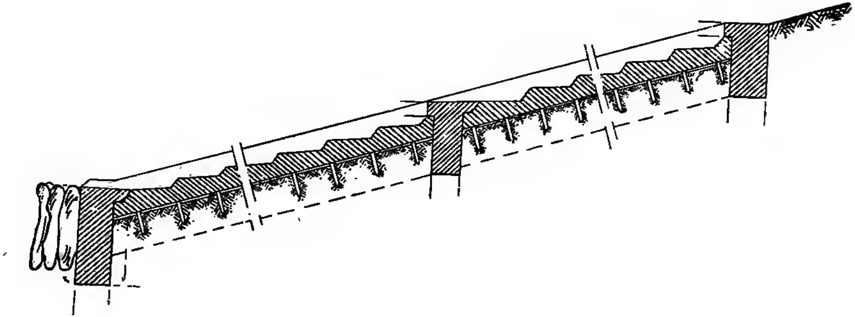

FIG. 30.—DE MURALT REINFORCED CONCRETE FACING.

This type of work has been largely used in Holland, especially for protecting the lower part of the dunes liable to erosion, and on which vegetation does not grow well.

In recent years the sea slopes of sand dunes on the coast of Holland have, in several places, been protected by a concrete facing constructed on the de Muralt patented system. This system, broadly speaking, embodies two methods of protecting the sea slopes. One system (Fig. 30) is used in exposed situations where wave action is felt, and the other, a lighter system, for less exposed situations. For protecting the exposed sea faces of dunes subject to erosion the heavier system is generally used.

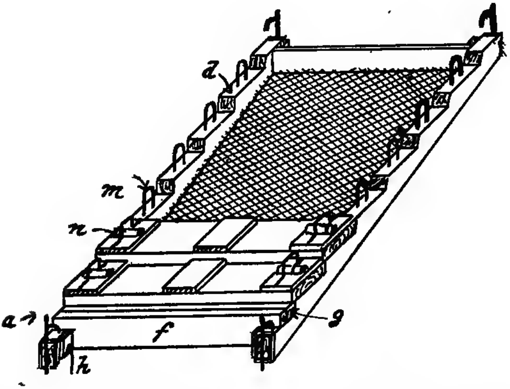

FIG. 31.—DE MURALT CONCRETE FACING. FORM FOR MAKING SLAB.

To prevent the cracking of the concrete facing, owing to change of temperature, the facing is divided into sections, the separate concrete slabs being kept in place by concrete beams. Both the slabs and beams are constructed in situ, the slabs being made first, and the beams subsequently built on the slabs.

Before the concrete work is commenced, the dune slope is levelled to an even gradient, and straw is then generally spread to a thickness of about 1 in. over the sand; this straw is kept in position by means of straw binders arranged in parallel lines at intervals of from 7 in. to 8 in.

After the slope has been thus levelled, two notched or stepped pieces of 4-in. by 5-in. timber, about 9 ft. long, are laid parallel to each other, 4 ft. 10 in. apart up the slope. The timber pieces *d* (Fig. 31) are secured in position by iron stakes *a* about 3 ft. 6 in. long, and a thin layer of concrete, about 1 in. thick, is then laid on the slope, and on this a sheet of expanded metal is laid, or other reinforcements of steel rods; a board *f* with a fillet *g* is then placed between the timbers *d* against the cleets *h* on the lowest steps. Boards are then placed on each step as the concrete is carried up the slope; these are kept in position by iron handles *m*, through which wedges *n* are driven. The concrete is well rammed in position, and above high-tide

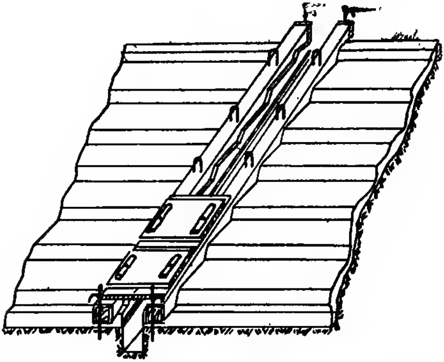

FIG. 32.—DE MURALT CONCRETE FACING. FORM FOR MAKING SLOPING BEAM.

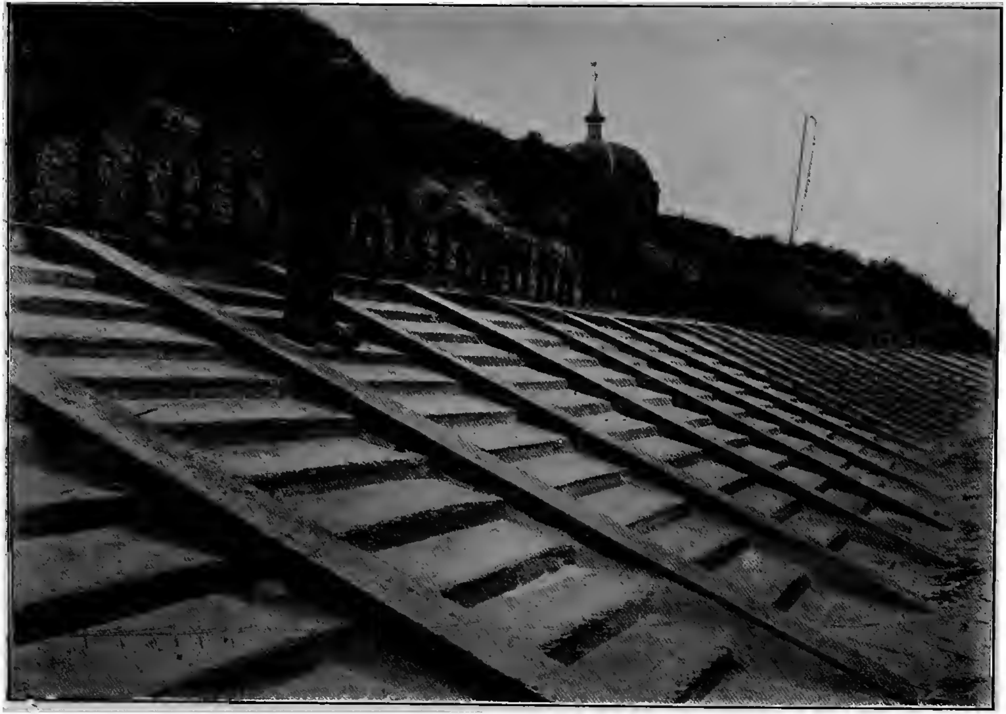

Fig. 33.—De Muralt Facing to Sand Dunes at Vlissingen, Holland.

level, in fine weather; the timber forms are removed a few minutes after concreting. Each completed slab is, approximately, 9 ft. long, 4 ft. 10 in. wide, and varies in thickness from 3 in. to 6 in.

Where the slope protection consists of more than one row of slabs, the slabs are concreted the whole way up the slope between two long notched or steeped timbers, the slabs being separated by a horizontal space. As soon as the slabs have hardened sufficiently, trenches are dug all round them to a depth of from 6 in. to 8 in. below the undersides of the slabs. Fig. 32 shows the trench and timber form for concreting the T beam on top of the slabs. The T beams are concreted in separate sections. Steel bars, $\frac{5}{16}$ in. in diameter, are placed near the bottom of the trench, and sheets of expanded metal No. 15 at the top in the head of the T, thus reinforcing the part of the beam which overlaps the slabs. At intervals of from 6 ft. to 9 ft. asphaltum joints are made in the T beams. The concrete for both the slabs and the beams is composed of 3 parts Portland cement, 4 parts sand, 1 part trass, and 7 parts gravel. Either sea or river water is used for making the concrete.

The inventor claims that his system of concrete facing to dune slopes is so much cheaper than basalt facings, which in the past have been much used, that the difference in cost capitalised, if put out at compound interest, would yield the capital originally expended in eleven years.

In his paper on "The Winning of Coastal Lands in Holland," read before the Institution of Civil Engineers, Mr. A. E. Carey, M.INST.C.E., described the ferro-concrete facing work constructed to protect the sand dunes adjoining the lighthouse at Renesse. The toe of the dunes became considerably eroded, and there was a risk of a breach in the line of dune defences. An artificial sand bank, 80 ft. wide, was thrown up at the foot of the dunes, and

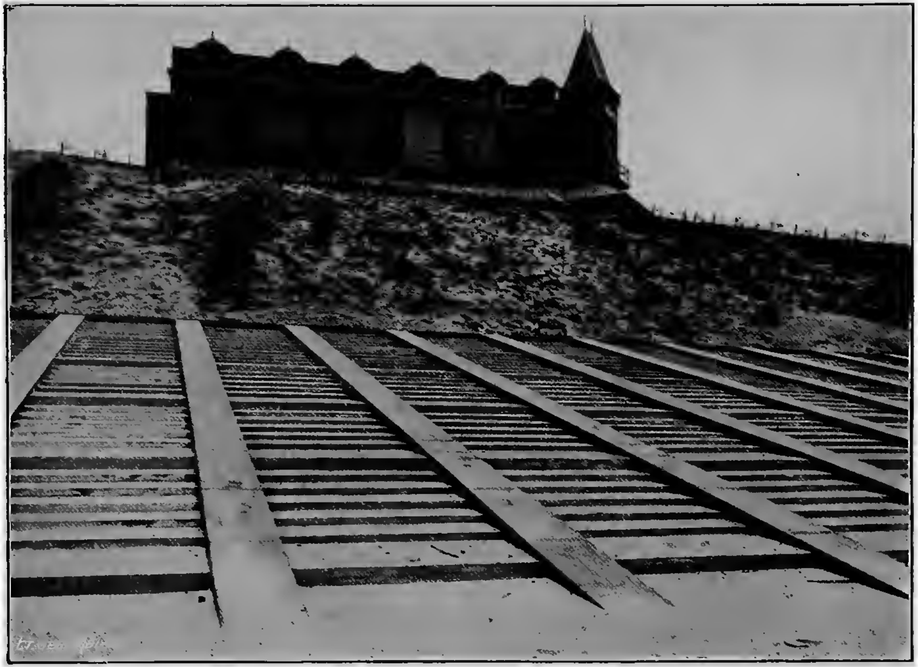

Fig. 34.—De Muralt Facing to Sand Dunes at Domburg, Holland.

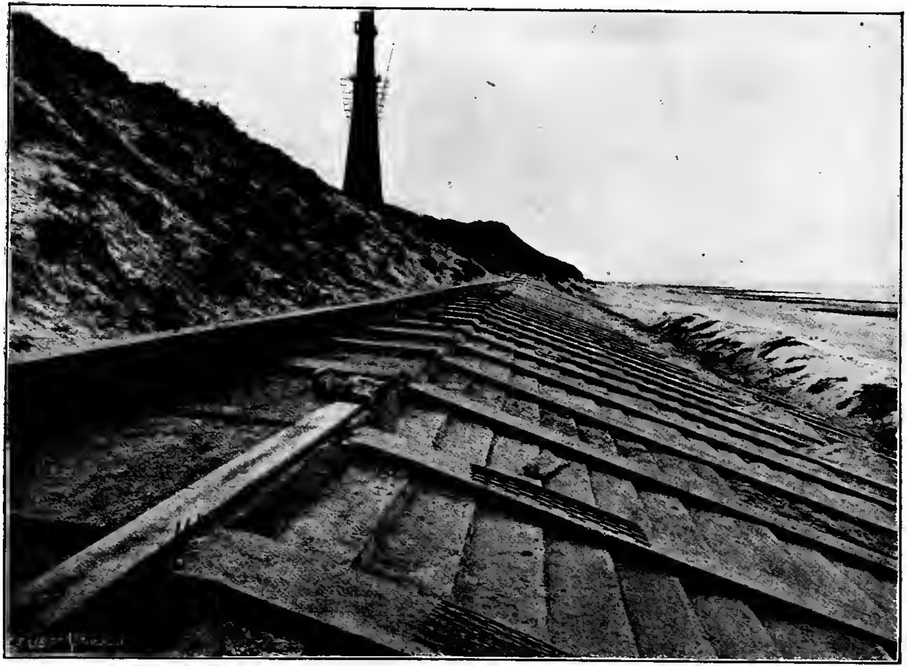

FIG. 35.—DE MURALT FACING TO SAND DUNES AT RENESSE, HOLLAND.

protected by a covering of concrete slabs on the de Muralt system. On the land side of the concrete slabbing tufts of helm grass were planted 12 in. apart. The length of the work originally carried out was 3,930 ft., but since the reading of Mr. Carey's paper it has been extended. After the work was completed erosion of the sea side of the dune ceased, and wind-blown sand has accumulated and partly hidden the concrete facing. The cost of the concrete slabbing was 4s. 11d. per square yard. The estimated cost of using basalt pitching on a clay foundation was 13s. 11d. per square yard.

CHAPTER X.

THE RECLAMATION OF SAND WASTES.

The process whereby drifting and barren sand dunes are prevented from trespassing over fertile country, and are transformed into wooded plains and grazing land, constitute a conquest by man over Nature, and are an instance of man's influence in modifying the earth's surface.

Of the advantages of reclaiming sand wastes landward of the littoral dune there can be no two opinions, and the efficiency of vegetation for this purpose is not open to question. Bare sand dunes which were advancing rapidly inland, overwhelming villages, churches, agricultural land and farms, have been reclaimed by planting of suitable trees and grasses. Where at one time there were miniature moving Saharas, there are now to be found valuable pine forests.

The measures which have to be taken to reclaim successfully a belt of bare coast sand dunes are:—

(1) The formation of an artificial coast dune to cut off the supply of sand from the foreshore.

(2) The levelling of small irregularities in the dunes so as to afford as few points as possible for the wind to attack.

(3) The sowing or planting the sand surface.

(4) The protection of the seeds or plants from sand drift until they become firmly established.

The construction and maintenance of the littoral dune has already been fully dealt with; but it cannot be too strongly pointed out that it is an essential part of any scheme for the reclamation of coast sand wastes. If an attempt is made to plant trees on the land margin of a bare sand waste where large dunes exist, without previously building up

the littoral dune, it will inevitably end in failure, and the advancing dunes will bury up the trees as shown in Figs. 13 and 14. The first thing to do is to form the littoral dune, and the planting in such places must be commenced on its seaward side, and be gradually extended inland until in course of time the whole belt of sand waste is reclaimed.

The wind is not capable of transporting sand above a certain height, and it is possible to build up a dune high enough to prevent any inland movement of sand from the foreshore, even if it is not covered with vegetation.

When sowing is adopted, the surface must be covered with branches of coniferous trees, heather, broom, furze, &c., or town refuse, to prevent it being disturbed while the seeds are germinating and firmly establishing themselves. If brushwood is used, the branches must be kept in place either by fastening them down with pegs or by placing shovelfuls of earth upon them. The covering must be allowed to remain on the sand, the plants pushing their way through it. If transplanting is carried out in preference to sowing, the surface between the plants is often covered with brushwood, or preferably by sods of turf. Where the temporary fixation of the sand is effected by turfing, the sods are usually arranged in rows of squares, within which the planting is done.

Generally speaking, in addition to the temporary fixing of the sand surface, which is required whether planting or sowing be adopted for the reclamation, it is necessary to build, at suitable intervals apart, continuous parallel rows of paling, brushwood or other fencing, at right angles to the direction of the prevalent onshore wind.

In places where there are wide belts of sand dunes inland of the littoral dune it is essential to reclaim the sand in comparatively narrow strips at

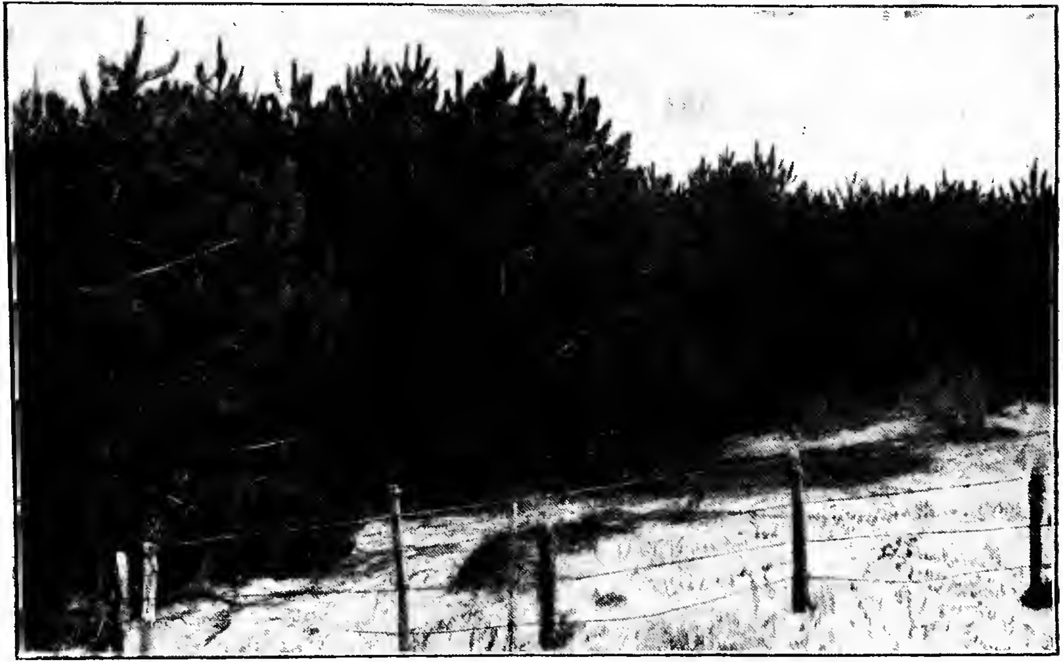

Fig. 37.—Burry Port, Carmarthen.

Typical growth of *Pinus Maritima* at the Lifeboat Plantation on the sand dunes.

a time, and to erect parallel lines of fencing. The distance between the parallel rows of fencing depends on local conditions; on level ground a fence 3 ft. high will afford shelter for about 200 ft., but on hilly ground they should not be more than 100 ft. apart, and on steep hillsides not more than 60 ft.* The fencing required is often made in the same way as that used on the littoral dune, and previously described.

In some places hedges are made of living trees and shrubs instead of the dead-wood fences. Such hedges have the advantage that, to some extent, they adjust themselves to a rising surface level due to sand drift. On the south of the mouth of the Coum River, within the boundaries of Madras City, hedges of *Casuarina equisetifolia* have been planted in the sand. They are about 5 ft. high, and are kept clipped like a yew hedge, so as to make them more efficient as sand screens.*

BURRY PORT, CARMARTHEN

A considerable tract of bare sand dunes has been reclaimed at the Ashburnham estate. This has been accomplished by planting marram grass in some cases and pine trees in others. The layer of sand on this part of the coast is of a very considerable depth. Borings for coal made in four or five places have shown the sand to be about 100 ft. thick.

Marram Plantations.—About 1887, and the following few years, a considerable tract of sand was planted with marram grass, the work becoming necessary owing to the sand drifting on to the cultivated land to the north. From time to time the area planted has been increased. The method of planting now adopted is as follows: tufts of marram are planted continuously in lines (Fig. 36), as experience has shown this method to be better than planting them at 8-in. or 10-in. intervals in the lines, which was formerly done. The photograph, taken in September, 1912, gives a good idea of one year's growth, as the grass shown was planted in the previous autumn.

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* Schlich's Manual of Forestry.

The cost of marram planting at Burry Port is about £7 10s. per acre, including digging up the grass and separating out the tufts ready for planting.

Experience here has proved the usefulness of marram grass for fixing the sand, and, in course of time, assisting the growth of a most useful herbage. In some places a mass of roots have been found to penetrate the sand 15 ft. below the surface, and the decay of these and the leaves helps to fertilise the sand, and to make a soil capable of growing other kinds of plants. Results at Burry Port seem to show that if the marram plantations are at any time completely covered by drifting sand owing to lack of protective fencing, the grass will perish; but that if even a small portion of the growth shows above the sand it will, in time, force its way through.

Pine Plantations.—About 1890 or 1891 a considerable area of blown sand was planted with *Pinus maritima*. The Towyn Burrows plantation of about 30 acres was made right in the middle of the sand dune area. The first step taken was to construct fencing, 6 ft. high, of posts, wire, boards and brushwood, to prevent sand drifting on to the area to be planted. The seed of the *Pinus maritima* was then sown in beds of about 12 ft. wide, with a space of from 4 ft. to 6 ft. between the beds. Brushwood branches were then thrown over the sand to prevent it from being blown away and birds and animals from eating the seed, the young trees being allowed to push their way through the dead wood. In this plantation most of the trees have not done well, although some of them have

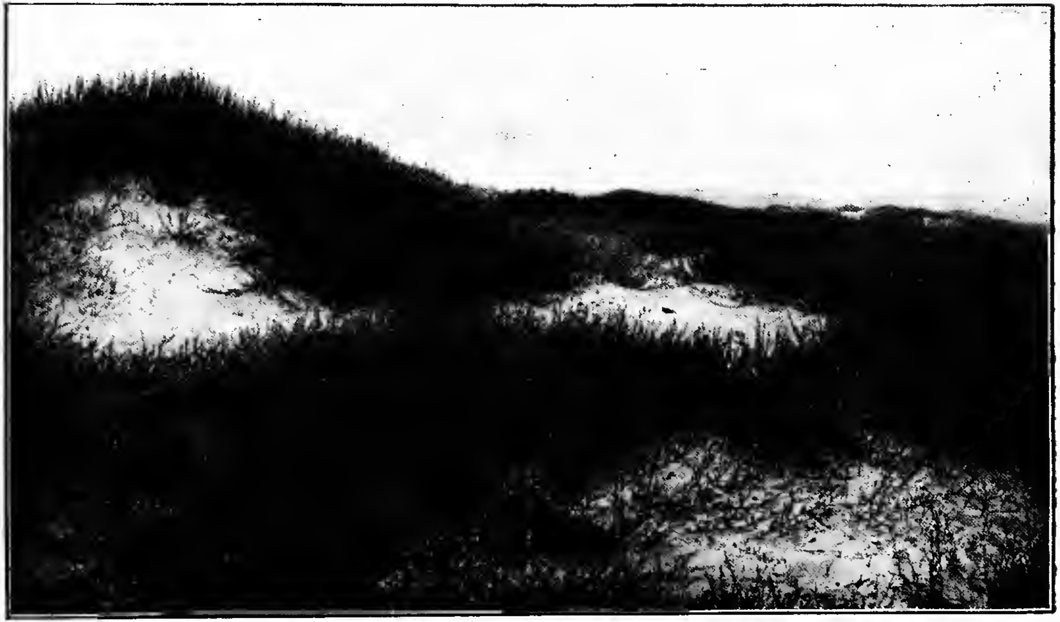

FIG. 38.—BURRY PORT, CARMARTHEN.

Dwarf willows (*Salix repens*) growing on the sand dunes grown very satisfactorily. One very noticeable thing is that some of the trees have evidently germinated much later than others, and are now only 3 ft. or 4 ft. high. In many cases where the pines have come up immediately they show vigorous growth.

The Lifeboat Plantation (Fig. 37), which is about ½ mile long, and, on the average, 450 ft. wide, was planted in 1892. This plantation was made on pure sea sand, in a situation sheltered from the strong sea winds, and has done very well. Many of the trees in 1912 were 15 ft. high and 4 ft. above the ground, and had a girth measurement of 17 in. to 19 in. Some of the best trees were 18 ft. high, and as much as 24 in. girth measurement 4 ft. above the ground.

In some places sand has drifted on to the plantation owing to inadequate fencing, but even where nearly buried in sand the trees have continued to grow as if the roots were immediately below the surface.

There is another small plantation on this estate known as the Cliffe Plantation, but in this case there is some soil mixed with the sand, and it appears that the seed of the pine was not sown, but that young trees were transplanted there.

Natural Reclamation.—On the dunes here, as elsewhere, there is a tendency for the sand wastes to become naturally clothed with vegetation if undisturbed by man or animals. In some places marram grass has sprung up, and areas of sand have become naturally reclaimed; in others the natural growth is inadequate.

A shrub which grows naturally on the sand dunes on this part of the coast is the sand willow (*Salix repens*, Fig. 38); it grows through the sand and adjusts itself to a rising surface level. In the opinion of Mr. Garnons Williams the sand willow is a very efficient plant for preventing sand

FIG. 39.—BURRY PORT, CARMARTHEN.

Bed of rock roses growing on the sand dunes.

drift, and he is inclined to the view that it is really a better one than marram grass for catching and holding drifting sand.

Other plants which grow in the sand are wild pansies, sea holly, dwarf bramble and rock rose. The latter plant (Fig. 39) not only effectively covers the bare sand, but in the spring and early summer the mass of white blooms is very picturesque.

HOLKHAM, NORFOLK.

Lord Leicester has planted here in the bare sands various kinds of pine trees at the rear of the coast protection dune.* In this case the chief object of planting was to obtain shelter and for ornament, and not to make a commercial profit out of the bare sand wastes. The results obtained, however, are a striking example of the utility of planting bare sands. The trees form a large fence, and prevent the inland drift of the sand. Where the pines are well established there is now no inland sand drift, but where there are no trees the sand is still drifting inland. About 250 acres of sand wastes have been planted with pines, which are inducing the formation of soil over the sand.

In the most exposed parts of the dunes the black Austrian pines (*Pinus Austriaca*) have done best, and in the more sheltered parts the Corsican pines have been found the most useful kind of plant; this latter variety have the advantage that rabbits will not destroy them. The Scotch pines (*Pinus sylvestris*) have also been planted with success. The sea pines (*Pinus maritima*) were found to bush, and their use has now been discarded.

In some of the older plantations the trees are now 35 ft. to 40 ft. high. The drooping lower branches of the Corsican pine cover a large space of ground round each tree. On the north sheltered

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* *Vide* Evidence of Mr. J. M. Wood, before the Royal Commission on Coast Erosion, and "Rural England," Vol. ii., by Sir H. Rider Haggard.

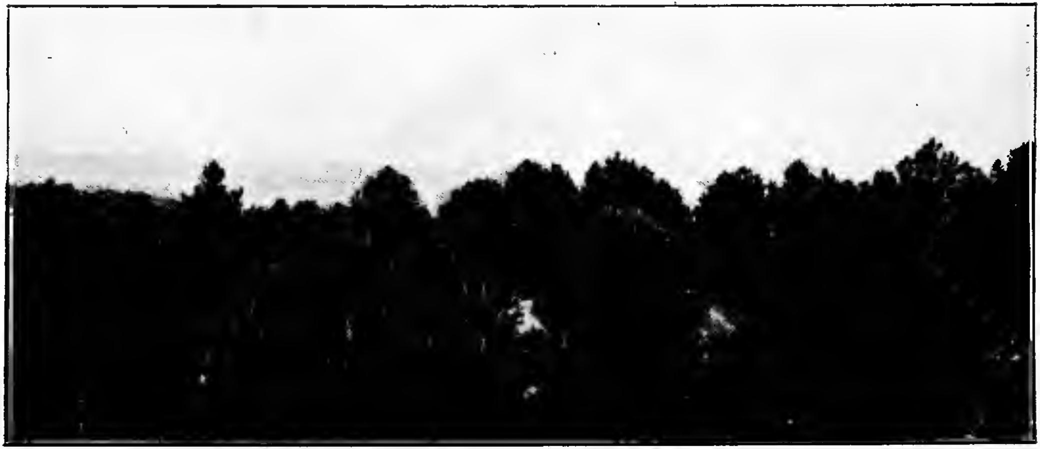

FIG. 40.—HOLKHAM, NORFOLK.

This view on the pine plantations on Lord Leicester's sand dunes on the east coast of England gives some idea of what may be done in the way of reclaiming belts of sand dunes and converting them into pine forests.

side of the dunes the trees seed freely, and are spreading naturally. They are generally put in about 8 yds. apart, and Austrian and Scotch pines are used for filling up. On the sea side, adjoining the protection dune, only Austrian pines are used. The cost of planting here is about 11s. per acre.

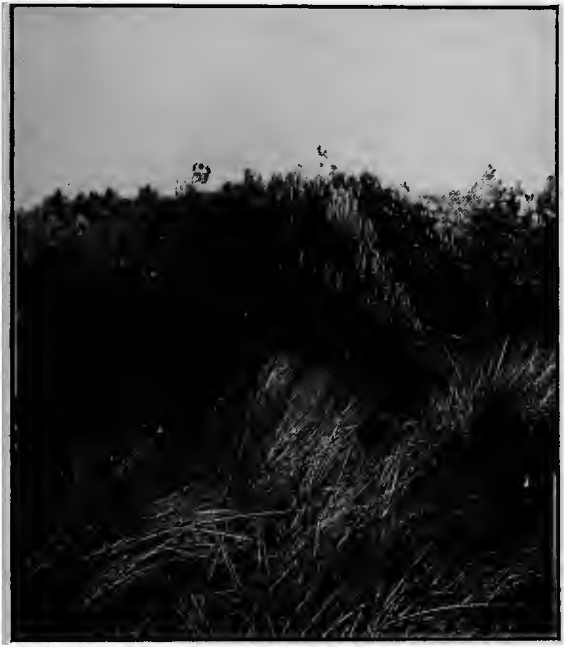

FIG. 41.—HOLKHAM, NORFOLK.

Young pine trees growing among marram grass on the sand dunes.

To guard against the possibility of fire causing havoc in the pine woods, the more recent plantations

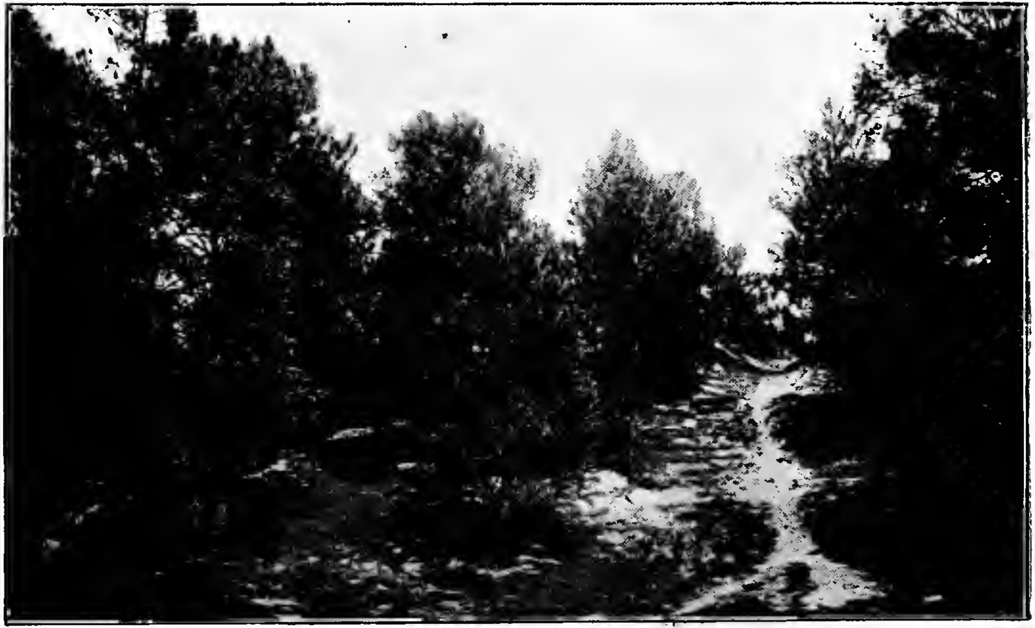

FIG. 42.—HOLKHAM, NORFOLK.
Pine tree growing on sand dunes.

have been divided up into blocks with spaces between, which are planted with marram grass.

PORT ERROL.

From 10 to 12 acres of bare sand have been planted with marram grass at Port Errol. To enable this to be done, from 3,000 ft. to 3,600 ft. of fencing, made of spars and wire with wheat straw plaited between the wires, was erected. This fencing checked the sand drift from the shore, and enabled the grass to take root and spread. The bare sands are now covered with a strong, healthy growth of grass, which is spreading naturally, and covering the surrounding bare sands.[*]

FRANCE.[†]

Immediately behind the coast protection dunes large areas of inland dunes and sand wastes have been fixed and reclaimed by the process of Brémontier as soon as the coast dune has been well established.

In this country the work of reclaiming coast sand dunes and sand wastes is undertaken by, or under the supervision of, the State.

By an ordinance passed in February, 1817, dune works, in the department of Gironde and Landes, were placed in charge of the Ministry of the Interior, and an annual credit of 90,000 francs was granted for this purpose. The care of established plantations was consigned to the Forest Department.

In 1862 a decree was passed by which the whole charge of works relating to coast sand dunes was placed in the care of the Forest Administration.[‡]

In 1780, previous to the passing of the State sand dune ordinances, M. Brémontier, availing himself of a suggestion made by a priest (the curate of Mimozon), devised the system of fixing the sand dunes, which is still called the Brémontier system. In 1796 he published the "Memoire sur les Dunes."*

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[*] Appendices Third Report Royal Commission on Coast Erosion.

[†] Brémontier, Memoires Sur les dunes, 1796; Hough, Report on Forestry, 1877 (U.S.A. Department of Agriculture); Journal of Royal Agricultural Society, 1875.

[‡] Les Codes de La Legislation, Forestiers, Paris, 1866; Hough, Report on Forestry, 1877 (U.S.A. Department of Agriculture).

The work of reclaiming the sand dunes in France may be divided into two parts: First, the formation of a large artificial littoral dune, and the fixing of this dune by vegetation, which has been previously described, and, secondly, the reclamation of the inland dune areas. It is found that no planting upon the dunes can be successfully undertaken without a properly maintained coast protection dune. This dune gives the necessary shelter to the inland area, and prevents the inland drift of further sand from the shore.

A law referring to the dunes was passed in 1801; it enacted that measures should be undertaken by the Government to fix and plant the dunes on the coast of Gascony, beginning with those of Le Teste.

A commission was appointed, oonsisting of the engineer-in-chief, M. Brémontier, a forest administrator, and three members of the Society of Science and Art and Belle-Lettres of Bordeaux (section of Agriculture). The members of these societies were to be appointed by the Prefect on the nomination of the society. The commission thus appointed was to direct and supervise the works, and funds were placed at its disposal by the State. In 1808 a similar commission was appointed for the department of Landes.

In 1810 a decree was issued directing the engineers of the Ponts et Chaussées to prepare plans for fixing and planting all coast dunes in France, whether the property of the State, communes or private persons. If the communes or individual owners were unable or unwilling to carry out the necessary works thus ordered, then they were car-

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*Reprinted in vol. i., first series, of "Annales des Ponts et Chaussées."

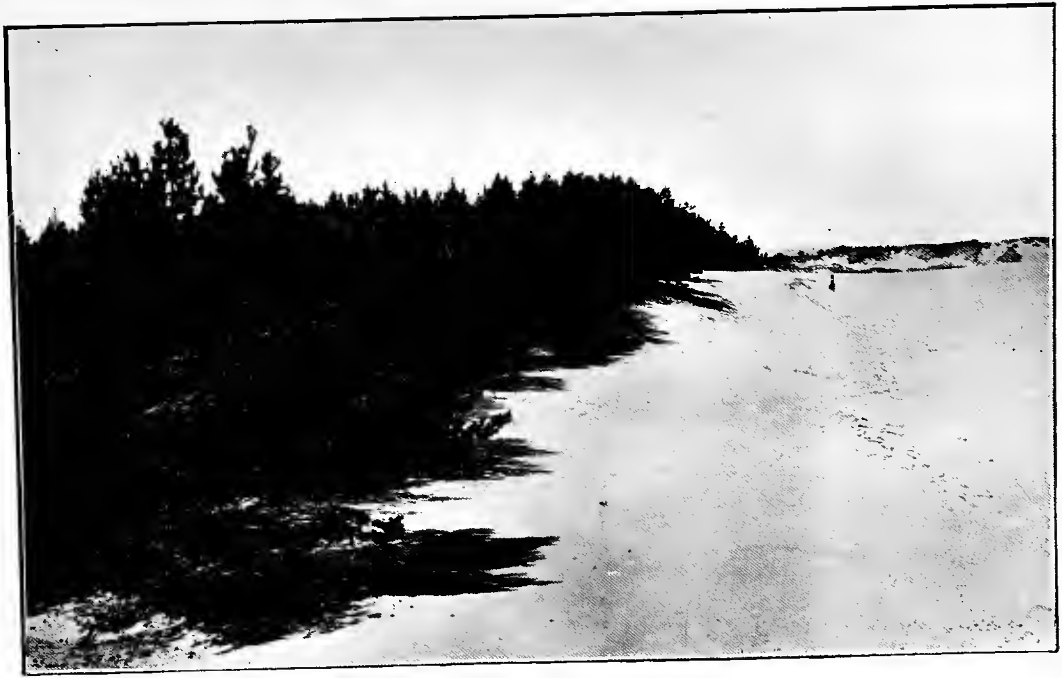

FIG. 43.—CULBIN SANDS.

Arrest of drifting sand by plantation of Scotch fir.

ried out by and at the expense of the State. In the latter case the State took any profits from cuttings, &c., until the whole cost of the work, together with interest thereon, was paid back, when the dunes were returned to their owners, with the obligation to maintain them satisfactorily. Owners were forbidden to cut down the trees planted, unless authorised to do so.

It has been found by experience that pine and other trees cannot be successfully transplanted on to the sand dunes in France, and seeding has therefore to be resorted to. Owing to the sand being constantly moved about by the wind, it is necessary to prevent it from moving while the seeds are growing. According to Brémontier's system, the first step taken is to sow broadcast the sand surface with a mixture of the seeds of the maritime pine (*Pinus pinaster*, *Pinus maritima*), the common broom, furze and marram grass, locally known as "gourbet."

Where the work is undertaken by the Forest Administration, 9·4 lb. of pine, 8·36 lb. of broom, and 3·76 lb. of marram seed are used per acre. The specification for the work of sowing the dunes in the commune of La Teste states that 18 lb. of pine, 7 lb. of broom and 4½ lb. of marram seed are to be used per acre when the dunes are very exposed to the action of sea winds.

In Schlich's "Manual of Forestry" it is stated that areas of dunes of about 300 ft. long by 60 ft. broad are sown at one time, and that between 1862 and 1874, 5,200 acres were sown in the Gironde at a cost of £30,646. The seeds used per acre for this work were: Cluster pine, 26 lb.; furze or gorse, 2½ lb.; genista, 2½ lb.; marram grass, 2½ lb.; seeds to attract insectivorous birds, 2½ lb.

In south-west France it is stated that *Quercus pedunculata* and *Q. Tozza* are mixed with the pines, and that in the depressions between the dunes the common elder, poplars and willows are grown.

According to the specification before referred to, the seeds are separately and evenly sown immediately before the spreading out of the brushwood, and the work done as far as possible between April 1st and October 30th. As soon as the seed is sown the surface of the sand is covered by spreading over it a layer of brushwood. The brushwood used for this purpose is cut fan-shaped; all the small branches or twigs which would prevent it being laid flat on the sand are cut off. The stems, where bent or twisted, are made straight by cutting notches half through them before they are laid. The branches are applied as evenly as possible on the sand surface, and laid overlapping one another like the feathers on the body of a bird. Shovelfuls of sand are thrown on top of the brush covering about 10 in. apart. The last row of the covering, at the end of a day's work, is secured by an additional load of sand to prevent the wind from getting under and scattering, perhaps, the work of several days.

On steep slopes the brushwood covering branches are cut and laid on as just described, but the thick ends of the branches are stuck into the sand to a depth of about 4 in.

For each acre of bare dunes 600 faggots of brushwood, of 22½ lb. each, are required, but if the surface is covered with marram grass only 300 faggots are used.

The branches to form the faggots should not have stems thicker than 1 in., and must have all the leaves on them. Between the beginning of November and the end of March the branches for the faggots should be cut at least twenty days before they are used, and for the rest of the year at least ten days.

Schlich's "Manual of Forestry" states that for the reclamation of dunes in Gironde 1,000 faggots, 3 ft. in girth and 5 ft. long, of furze, broom, heather or pine branches were used per acre for covering the seed, furze faggots being preferred. The branches are placed in rows with their lower ends towards the sea, so that each succeeding row of branches partly covers the preceding one like slates on a roof. Spadefuls of sand are thrown on the covering branches at intervals of 2 ft.

Brushwood protection must be kept in place about four years, and its maintenance is the chief work during this period. In some cases it is found necessary to protect fresh sowings from the encroachment of drifting sand by erecting at intervals lines of palisade fencing, wattled fencing, or brushwood fencing in addition to the brushwood covering. In the commune of La Teste the palisade fencing is made of 1-in. tarred pine wood boards, 5 ft. long and 6 in. to 8 in. wide. These are driven 2 ft. into the sand, a space of ¾ in. being left between each board, or, if wattled fencing is used, it may be either single or double. The single fencing is made of a row of stakes about 2½ in. in diameter and 5 ft. long, driven 1 ft. 8 in. into the sand, the stakes being placed 1 ft. 8 in. from centre to centre. The space between the stakes is wattled to a height of 3 ft. 4 in. above the sand. For double wattle fencing the stakes are only wattled to a height of 3 ft. 4 in. above the sand to commence with, an equal height being left for a second wattling when the sand has accumulated to the top of the first. The brushwood fencing (cordons) is made with bundles of picked brushwood, about 8 in. in diameter at the bottom and 28 in. at least in height. These are planted in fives (*en quinconce*), in two or three rows as required, and fixed about 1 ft. into the ground.

The broom seed comes up before the pine seed, and covers the sand surface with a growth of vegetation which is a more perfect protection than the brushwood covering which first gave it shelter.

When the pine plants have come up slowly under the shelter of the broom, and have grown to a certain size, they choke the broom plants which first protected them. The broom plants being no longer of any use, they are removed and used as brushwood for covering up newly sown areas.

After the pines have thus killed the broom no further work is required except to clear out the plantation in proportion to the growth, so as to secure the healthiness of the remaining trees. The produce of these thinnings, in conjunction with the broom plants, is used as brushwood for covering freshly planted areas.

The cost of fixing the sand dunes in France by pine plantation varies considerably. If the supply of brushwood necessary for covering the newly sown seeds can be got from plantations already established the cost is greatly reduced. The average cost of sowing the dunes, including the brushwood covering and erection of the necessary fencing, is stated to be about £2 10s. per acre when the brushwood is obtained from neighbouring plantations. In some cases the cost of reclamation is about £8 5s. per acre.

As soon as established the pine plantations on the dunes have a considerable commercial value. The Forest Administration in France make a normal profit from the dunes of about 10s. per acre when planted and brought to the full capacity of production. The value of privately owned dunes, when the plantations are properly established, is about £16 an acre.

When the pine trees are from eighteen to twenty years of age they commence yielding turpentine and resin. A considerable annual revenue is obtained from this, independently of the value of the timber from which these are produced.* A very large area of drifting and useless sand dunes have been reclaimed and converted by Brémontier's system into valuable plantations, which now yield a large annual revenue.

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* Travers, "Transactions" of the New Zealand Institute, vol. xiv., 1881.

Between 1788 and 1895 about 800,000 acres of sand dunes in the department of Landes and Gironde have been fixed, and pine forests formed thereon. In 1893 the expenditure for new work and for maintaining the dunes which had previously been fixed was £8,400.*

Before their reclamation the sand dunes were rapidly drifting inland, causing coast erosion and the devastation of large areas of fertile land. The reclamation has therefore saved a large area of valuable country from destruction with which it was threatened. It has secured an incidental advantage beyond the immediate area of the sands planted with pines, as shallow lagoons which existed behind the dunes in some places have gradually become dry, and the cultivation of large areas has thus become possible.

In the neighbourhood of Cape Breton a method of reclaiming the sand dunes, and at the same time rendering them immediately productive, has been followed for two and a-half centuries, and is about the oldest well-authenticated method of reclaiming sand dunes. This method consists of planting vineyards on the dunes which are protected all round by hedges of broom (*Erica scoparia*). This method is, of course, only applicable in a few places where the climate is suitable.

The vines are grown in plantations about 30 ft. by 40 ft., each one being surrounded by a hedge of broom. The grapes produced from the sand dune plantations are among the finest grown in France. The dune surface is alternately covered every year with a coating of manure and sand. The sand thus applied, every alternate year, raises the surface about 4 in. or 5 in. Every year the vines are cut down to three or four shoots, and the raising of the surface covers the old stocks. When buried they send out new shoots, and although the vineyards may be two generations old, they always have a youthful appearance.*

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* **Schlick's "Manual of Forestry," vol. iv.**

In the South of France, and also in England, Russia and India, *Ailanthus glandulosa* will grow well on sand dunes.

GERMANY.

In 1795 Soren Bjorn, a native of Denmark, was commissioned to undertake the reclamation of the coast dunes of Prussia, and, excepting the period between 1807 and 1817, this work has been continued ever since. The methods adopted there were very similar to those used in Denmark.

In 1850, between the Vistula and Kahlberg rivers, 6,300 acres of sand dunes were fixed, about 1,900 acres of which were planted with pines and birches. At the same time about 8,000 acres of dunes between Kahlberg and the eastern boundary of Prussia were reclaimed.†

Prussia, between 1884 and 1887, spent about £3,100 a year in fixing the sand dunes on the Baltic coast,‡ and during this time 230 acres were fixed with grass and 608 acres stocked with trees.

The sands inland of the coast protection dunes have been planted in places with Scotch pines. They are transplanted on to the dunes when from two to four years old, and are dug up with special spades, care being taken to leave a ball of undisturbed earth round the roots. Holes at intervals of from 1 ft. to 1½ ft., in rows 2½ ft. to 3 ft. apart, at right angles to the direction of the prevalent wind, are dug in the sand, just large enough to take the ball of earth on the roots, and the sand is then firmly pressed down round the roots of the young trees. The cost of planting is about £4 5s. an acre. The maritime pine has been tried, but it does not do well, the climate being too cold.*

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* Bortis, quoted by Marsh in "Earth and Man."
† Kruse, "Dünebau."
‡ Schlich's "Manual of Forestry," vol. iv.

Schlich, in his "Manual of Forestry," states that long-rooted yearling pines, in some places in Prussia, are planted on the dunes after marram grass has got a hold. They are put in about 1 ft. apart, in rows 3 ft. apart, care being taken to disturb the sand as little as possible. The mountain pine is found the best for fixing the sand, other trees being afterwards planted among the pines. Cuttings of poplars and willows are also put in.

In Schleswig, where the sand contains little flakes of mica, beech and silver firs are grown on the sand dunes.†

Sods are chiefly used in Germany for temporarily covering the sand to enable the planting to be successfully carried out. The sods are laid in the autumn or spring after a heavy rain, with the earthy side downwards, the sods being firmly pressed down.

Partial sodding costs from £1 to £3 an acre, with daily labour at 1s. 10d. Covering with branches costs somewhat less, using from forty to fifty cartloads per acre. As soon as the sods have been laid, the young pine trees are put in. A mixture of $\frac{2}{3}$ peat with 2 per cent unslaked lime, and $\frac{1}{3}$ sand is used, in some places, to fill the holes round the roots of the pine trees when they are planted.

The dune forests in this country are strictly protected against wanton injury. Article 366A of the German Criminal Code punishes contraventions of the dune forest regulations by fines up to £7 10s., or imprisonment.

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* Hough, Report on Forestry, U.S.A. Department of Agriculture, 1877; Schlich's "Manual of Forestry," vol. iv.

† Schlich's "Manual of Forestry."

HOLLAND.

In the neighbourhood of Schoorl the Dutch Government have undertaken the work of planting the sand dunes. On this part of the coast the dunes are very broad, and the afforestation has been carried out with the object of preventing sand from moving inland and inundating pasture lands. A tentative experiment was made in planting between the years 1866 and 1868, but it was not until 1894 that a comprehensive scheme was carried out. The chief trees planted have been various species of pine, chiefly the Corsican, Austrian and maritime. The cost of planting has averaged 200 florins per hectare. The trees have thrived well, except in very exposed parts, and the work is considered a success.*

BELGIUM.

In a report made in 1877 on the tree plantations on the Belgian coast sand dunes, the chief engineer stated that at La Penne, between Blankenberg and Ostend, conifers had not done very well. After forty years' growth the Weymouth, Scotch and Austrian pines were only about 8 in. in diameter and 13 ft. in height. The elder, poplar, birch and ash grew much better in the depression between the dunes.

On the sand dunes on M. Mortiere's estate at La Panne the aspen poplar has grown well, and paper has been manufactured from the sap of this tree grown on the sand dunes. At the International Horticultural Exhibition, held in Amsterdam in 1877, a specimen of the paper was shown, made from trees four years old and grown on the sand dunes at La Penne.†

In recent years the coast sand dunes between Clemskerke and Wenduyne have been planted with various species of trees. The plantations were made

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* Appendix to Third Report of Royal Commission on Coast Erosion

† Hough, Report on Forestry, U.S.A. Department of Agriculture 1877.

long strip of sand dunes,* the tendency here being for the sand to accumulate and move inland. To prevent the sand drift across the road, clumps of *Casuarina* and other trees have been put in at intervals, and a hedge of *Casuarina equisetifolia*, about 5 ft. high, planted on the sea side of the road. The hedge is kept clipped like a yew hedge, so as to make it more efficient as a sand screen. When the road is thus protected sand dunes have formed seaward of the road.

For accumulating sand and forming a coast dune *Spinifex squarrosus*, a kind of grass, is found most useful. This plant has burrowing stems, often many yards in length. Screw pines (*Pandanus tectorius*) are also very useful for accumulating and reclaiming the sand. The efficiency of these trees for this purpose is largely due to their aerial roots. The screw pines have a considerable number of these roots; they start as little knots on the trunk, several feet above the ground level.

For several reasons coconut trees alone are not so suitable for planting on the shore at Madras as they are in other places. The direct reclamation of the sandy belt at Madras seems to have been most satisfactorily brought about by planting *Casuarina equisetifolia*. In places where the sand has already been raised and fixed by grasses, the *Casuarina* trees can be planted with great advantage. It is best, however, not to plant them on a rising surface, as it may prejudice the chance of young trees establishing themselves, and necessitate artificial watering for a considerable period. In some places young trees have done well, even when planted on rising ground, if watered for one or two years; but this is expensive when water has to be brought in chatties by coolies. Full-grown *Casuarina* trees have a considerable commercial value, the timber being used for scaffold poles and for other purposes.

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* R. Ryves, *The Engineer*, February 2nd, 1912.

SOUTH AFRICA.*

Cape Flats.—At the Cape Flats considerable areas of drifting sand dunes have been reclaimed by the Government. The first system tried was to construct parallel rows of screens about 12 ft. high and 484 yds. apart, and to plant the enclosed sands with Hottentot figs (*Mesembryanthemum edule*). This method was quite successful in arresting the movement of the sands, but these trees are of little or no commercial value.

There are no trees indigenous to Cape Colony which are useful for reclaiming sand dunes and at the same time of commercial value, and it was therefore decided to try various kinds of Australian trees, and the varieties which were found to grow best in the sand were the *Acacia saligna* and *Acacia cyclopis*. The *Hakea, Fabricia* and *Callitris* were also introduced and found to grow well, but these plants have no commercial value, and are chiefly of use for forming hedges and wind breaks to protect other plants and trees.

In course of time the system of reclamation above described was greatly improved upon. It was found better to make the screen lower, and to put the parallel rows near together; the height was reduced to from 3 ft. to 4 ft., and the distance apart to 8 ft. These screens are placed along the dunes at right angles to the prevalent onshore wind. They are formed of bush, the stems being planted in the sand to a depth of about 1 ft.; a crowbar is used to make the holes so as to disturb the sand as little as possible. The stems are placed close enough together to form a thick and compact hedge. The best kind of brush to use for the screen is that which retains the leaves for a considerable time after being cut. The cost of erecting these screens or hedges is about 1d. per lineal yard. The work is commenced on the sea side, the rule being always to work with the wind and not against it. Between the rows of screens seeds of different trees (acacias, pines, &c.) and grasses are sown and raked in.

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* C. H. D. Braine, "Minutes of Proceedings" Institution of Civil Engineers, vol. cl., and Evidence of Mr. W. Shield, M.I.C.E., before Royal Commission on Coast Erosion, November, 1906.

The pypgrass (*Ehrharta gigantea*) is one of the best grasses for planting sands in Cape Colony.* It has underground stalks many feet long from which, at intervals of about 1 ft., stalks 2 ft. to 3 ft. high grow up. This grass also multiplies by seed.

In some places the fences were constructed of poling boards instead of brushwood, the poling boards being driven into the sand, and a space of about 4 in. left between each board. The boards are allowed to project about 2 ft. above the sand, and are raised from time to time as the sand accumulates. Seeds are planted between the rows of screens as before mentioned. On other parts of the dunes the reclamation has been brought about by sowing broadcast the seeds of suitable trees and grasses, and then covering over the surface of the sand with refuse from Cape Town.

It is found that after eight years a return is obtained from the plantations by the sale of posts, bark and firewood. Mr. Shield, M.INST.C.E., states that the Cape Flats are now covered with pine trees and other vegetation, and that the land (which was formerly drifting and useless sand dunes) is now worth £1,000 an acre as sites for building plots. In 1889, 25 acres of sand dunes were planted with pypgrass and 40 acres with marram grass. The cost of this work came out at just over £3 per acre.

Port Elizabeth.—In 1890 Mr. I. S. Lister, of the Forest Department, was called in to advise on the best means of reclaiming the drifting sand dunes at Port Elizabeth, and he recommended the adoption there of the system he had used at the Cape Flats in 1887—that is, sowing broadcast on the sands the seeds of suitable trees and grasses, and then spreading over the sands a covering of town refuse. This work was eventually carried out by the Forest Department. To every acre of bare sand about 35 lb. of mixture of seeds of *Acacia cyclopis*, *Acacia saligna*, *Acacia pycnautha*, *Pinus halepensis*, and rye, pypgrass, sunflower and lucerne. After the seeds have been well raked in, the town refuse is evenly spread over the sand surface. Other useful grasses for growing on the sand dunes are *Cynodon dactylon* and *Sporoborlus matrella.*

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* Report of Colonial Botanist, Cape of Good Hope, 1865.

In addition to the method of reclamation above described, considerable areas of the bare sands at Port Elizabeth have been reclaimed by sowing broadcast over the sand the seeds of suitable trees, shrubs and grasses, and then covering over the surface with brushwood. The cut branches are laid on the sand side by side, or slightly overlapping, with all the butt ends pointing towards the direction of the prevalent onshore wind, the ends of each row being covered by the tips of the branches of the back row.

A considerable number of seedling trees and cut tings have also been planted on the sands. Between 1895 and 1899 over 60,000 trees and cuttings were planted annually, according to the official returns. The trees found most successful for this purpose were *Tamarix*, *Pinus halepensis*, *Acacia saligna* and *Cupressus macrocarpa.*

Efforts have been made, but without much success, to introduce *Pinus pinaster*, which has been so successfully used on the French dunes.

In many cases it is necessary, before planting or sowing the selected area of sand, to protect it from encroachment of sand from unplanted areas. For this purpose protecting screens, constructed of stakes interlaced with brushwood, are used. The screens have continually to be raised as the sand piles up against them.

Cost of Reclamation.—The average cost of reclaiming the sand dunes at Eerste River was about £10 per acre. The cost of reclamation by sowing and then covering with brushwood was £4 an acre at Port Elizabeth, where brushwood was plentiful, and convict labour at 1s. a day was used.

AMERICA.

San Francisco.—The Government Engineer Corps and the Board of Park Commissioners have carried out the work of reclaiming a considerable area of sand dunes at San Francisco.* The Park Commissioners have transformed an area of 1,040 acres of barren drifting sand, which was rapidly moving inland, into the beautiful park now known as the Golden Gate Park. The process of reclamation consisted of first planting marram grass and wild lupins, which quickly took root, and prevented any further movement of the sand. These prepared the surface, and when they had taken a good hold, it was possible to plant various trees and shrubs, which would not have grown so well in shifting sand. After the trees had grown to a certain extent, other kinds of flowers and shrubs were put in, as the conditions were gradually altered to suit their requirements. Thus, by a gradual process, and the use of different plants and grasses—some of which were put in temporarily to prepare the way for the next series—a highly satisfactory result was achieved which would not have been attained by planting, in the first instance, the higher grass, flowering plants and shrubs which now grow in the park.

By gradual transplanting the whole of the area of 1,040 acres was reclaimed, and in 1885 there were 250,000 cypress and pine trees, and numerous flowers and shrubs.

The work of reclamation by the Government Corps of Army Engineers here was of more recent date. Particulars of the work carried out are given in the chief engineer's report for 1900. About three-quarters of the Government reservation consisted of barren, shifting sand dunes, the other quarter being covered with a growth of "bunch" grass.

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* Report of Board of Park Commissioners, San Francisco, 1885, and Report of Chief Engineer U.S. Army, 1900, Part 1.

The first step taken to reclaim the shifting sands was to transplant "bunch" grass there from the Park Commissioners' property. The grass was put in in small tufts, about 2 ft. 6 in. apart, each one having its roots and tops trimmed off before being planted in holes, about 3 in. deep, in the sand. Thirty-five acres were thus planted, all doing well, although growing rather slowly at first; but once it had made a start it spread rapidly, sending out shoots to a depth of 7 ft. or 8 ft.

To prevent the sand drifting about while the "bunch" grass was getting a start, the whole area was sown with oats, which come up on the sand in a day or two, and grow well while the rainy season lasts, but die as soon as the dry season commences.

When the grass had got a good hold, about 800 spruce trees from eight to ten years old were transplanted from the Presidio Reservation, but they were not a success. These trees had been growing in pure sand, and consequently no soil could be kept round their roots in moving them. As a general rule, it is impossible to transplant trees of such an age on to sand dunes successfully.

When it was found that the spruce trees were not likely to be a success, 4,000 young eucalyptus trees were purchased at a cost of $18 per 1,000, and were planted. Practically all of these have grown well. They were only 10 in. or 12 in. high in 1900, but the eucalyptus grow very quickly, and become large trees in the course of four or five years.

St. Augustine's, Florida.—The Corps of Army Engineers have undertaken the work of planting Bermuda grass (*Cynodon dactylon*) on the loose, bare sands here, and it has been found to serve the purpose very well. It creeps over the sand in zigzag form, sending out very long runners which have joints at each angle, 6 in. or 8in. apart; from each joint a root strikes into the sand, and a network is soon formed, which consolidates and binds together the loose sand. It has short, rather flat leaves and flowering shoots which grow a few inches high and bear seed.

Lake Michigan.—The inland movement of the sand dunes, which are found here up to 200 ft. high, has in the past done great damage, and devastated considerable areas of fertile country. In this district the beach grass (*Calamgrostis arenaria*) and *C. longifolia* thrives well in the sand, and affords an excellent means of fixing the dunes. The wild grape also flourishes well, and Mr. Hough thinks it might be planted with great advantage.

Charlottesville, Virginia.—A Mr. Jefferson introduced the furze (*Ulex Europaeus*) into this district, and it has now spread abundantly, and is growing well on the sand dunes.

VICTORIA.*

Port Fairy and Port Melbourne.—The country at Port Fairy affords practical evidence of the value of marram grass† for fixing and reclaiming sand dunes and sand wastes. The country in this district is among the most valuable land in Victoria. Previous to the planting of marram grass the sand dunes were rapidly moving inland, and threatened to absorb large tracts of fertile land. The marram grass has been very successful in fixing the sand and reclaiming the dunes. In places where a few years ago there was not a vestige of vegetation there now exist meadows of marram grass growing, in some parts, to a height of 4 ft. When properly established these marram plantations make a valuable pasturage, the grass being eagerly devoured by cattle.

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* *Vide* "The Use of Marram Grass as a Sand Stay," by H. V. Champion, M.I.C.E.; "Proceedings" of the Victoria Institute of Engineers, and U.S.A. Forestry Department; Report by Mr. F. B. Hough, 1877.

† There seems to be some doubt whether the grass referred to is the same as the marram grass (*Psamma arenaria*) which grows in Europe.

The seed of the marram grass was first introduced into Victoria by Baron von Mueller, but for the planting at Port Fairy the roots were, in the first instance, imported from India.

It is often stated that marram and other grasses cannot be grown on very exposed sand dunes on the east coast of England and elsewhere, and it is not an uncommon sight to see large areas of dunes only partially covered by vegetation.

Much of the failure is, undoubtedly, due to want of system in the planting, and through not taking into consideration the direction of the prevalent wind and other important factors.

When first tried at Port Fairy the marram grass was a failure, and no doubt would have continued to be so but for the perseverance of Mr. S. Avory, the park ranger. Success was only achieved after carefully studying the prevailing conditions. The results eventually obtained, however, have well repaid the trouble. The marram grass when once properly established grows luxuriantly, and is practically indestructible; cutting and eating off only seem to make it thrive.

At Port Fairy and Port Melbourne Mr. Avory's system of planting was adopted. This was commenced in the cool season, very soon after Easter, in Victoria. Tufts of marram grass were planted in parallel rows 6 ft. apart, and at right angles to the direction of the prevalent onshore wind, each tuft in the row being 2 ft. from the next. At Port Melbourne Mr. Avory started work with fourteen men and a foreman. After the foreman had marked out the line, two men commenced work together. The leader dug the holes in the sand, and the follower put in the plants and stamped the filling round them, care being taken not to injure the plants.

The sand for filling was thrown back by the leader from the hole he was excavating in front. The follower carried under his left arm as many plants as he could conveniently hold, the plants being previously arranged so that the roots were at the same level. Each tuft consisted of as many plants as could be withdrawn from the bundle by the right hand. Any number of men can thus be employed, but they must work in pairs. After planting, all sand filling above the general ground level was levelled down. If any of the plants in the tuft were found to straggle over after they were put in they were drawn together and loosely tied on top. Long-handled spades were used for digging the holes, and also as a gauge for the distance between the rows.

The planting in this case was commenced at the landward or sheltered side of the sand dunes, and gradually worked towards the sea shore. The cost of planting 27 acres at Port Melbourne was as follows:—

	£	s.	d.
40 tons of marram grass at Port Fairy Wharf at £1 10s.	60	0	0
Freight, 10s per ton	20	0	0
Agent's charges	2	0	0
Landing at Port Melbourne Wharf and carting to site...	9	0	0
Planting, 14 men at 6s. per day, one foreman at 8s.	84	13	8
Expenses of Mr. Avory	6	0	0
	£181	13	8

The cost per acre of reclaiming the sand dunes, therefore, was £6 14s. 7d., exclusive of fencing. The cost of planting only was £3 7s. 2d. per acre at Port Melbourne, as compared with £2 per acre at Port Fairy.

At Melbourne the fencing to the marram plantations consists of posts and three wires, having 18-ft. panels, with stiffening pieces in the middle. It costs about 7s. 3d. per chain. It is very light fencing, but found strong enough for the purpose—that is, to keep off cattle for the first three years after planting.

Mr. Avory found that at Port Fairy one head of cattle per acre could be kept in the marram plantations for five months per annum, during the cool season, three years after planting, when the growth is vigorous. In countries with severe frosts this procedure might not be able to be carried out without enfeebling the growth. For the first two years after planting it is most important to see that the growth of the plants is not interfered with by animals, or hampered in any way. After three years the fencing is removed, and the presence of cattle then benefits the ground, and prepares it for other plants and grasses, which then take root and thrive with the marram grass. The tops of the marram grass can be cut. They make nutritious fodder.

Between 1883 and 1902 about 3,000 acres of pure sand dunes in this district have not only been fixed and reclaimed, but have also been made into valuable grazing land. In 1901 the Port Fairy Council took £200 in grazing rents, sold £424 worth of marram plants, and spent £384 in labour on their plantations, when other work in the district was slack. The nett profit on the Port Fairy Council's dune for one year, therefore, was £240.

Some years ago, before marram grass was introduced, a considerable area of sand wastes in the neighbourhood of Port Melbourne was reclaimed by the Public Works Department. For this work silt was carted to the sand dunes, and evenly spread over the sand to a depth of about 4 in., 540 cub. yds. of silt being used per acre. The cost of getting the silt, carting to the site, spreading, &c., was 1s. per cube yard. This works out at £27 per acre for reclamation, or about four times as much as the cost of reclaiming by planting marram grass.

PLACES WHERE SAND WASTES MIGHT BE RECLAIMED.

While much has been done in the way of reclaiming sand dunes, especially in France, there are still large areas of coast sand wastes which might profitably be reclaimed, and still larger areas of sand dunes which are only partially covered by natural vegetation, and which might be made into good grazing land at a small cost.

In the Vale of Glamorgan there is a considerable area of sand dunes which presents an interesting field for dune afforestation.* The Baglan, Margam, Kenfig and Merthyr-mawr sand dunes contain several square miles of waste land, much of which, according to a report of the Board of Agriculture, is capable of growing trees, and thus improving the soil, retaining the sand from drifting, providing shelter and employment, and, in course of time, profit. Pinaster and Corsican pines would probably both do well in the bare sand; but some of the dunes, particularly the large area at Kenfig, contain much humus.

In his report to the Board of Agriculture Mr. D. W. Drummond says: "Were these dunes in the hands of, say, the French Government, they would no doubt ere this have been afforested, and now providing the very class of timber which is being grown under similar conditions in Western France, and to be seen in any colliery yard in the county of Glamorgan, providing employment, profit and enrichment of the soil, while our bare hillsides are looking profitlessly on."

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* *Vide* Report on land in Glamorgan suitable for afforestation, prepared for the Royal Commission on Coast Erosion by the Board of Agriculture.

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